

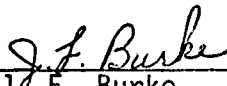
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SIMULATOR SOFTWARE CONCEPTUAL DESIGN
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SIMULATION PRODUCTS

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SHUTTLE MISSION SIMULATOR
SOFTWARE CONCEPTUAL DESIGN

3/23/73



J. F. Burke
Principal Investigator
SMS Definition Study

This document is submitted in compliance with Line Item No. 6 of the Data Requirements List as Type I Data, Contract NAS 9-12836.


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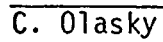
SHUTTLE MISSION SIMULATOR
SOFTWARE CONCEPTUAL DESIGN

Prepared by:


D. E. Small

Approved by:


J. F. Burke
Principal Investigator
SMS Definition Study


C. Olasky
NASA Technical Manager
Contracting Officer's Representative

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SCOPE

This document provides Software Conceptual Designs (SCD) as approaches to meeting the simulator requirements of the Shuttle Mission Simulator Requirements (SMSR) report. These designs are conceptual only and are not meant to imply necessarily the best solution to each problem, but only to allow sizing the computer complex and to provide at least one solution to each problem.

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1.0 Introduction

For purposes of the study, the major areas of the SCD were divided into Malfunction Insertion, Flight Software, Applications Software, and System Software. Failure Insertion Concepts is generally applicable to all three of the other areas since this is the means of introducing off-nominal performance and is implemented by Systems Software inputs to the Application Software. Flight Software refers to the software developed for real world use. This includes the on-board computers for Guidance, Navigation and Control, the Main Engines and Display. System software includes the required simulator control systems, as well as the data management system. The computer complex includes the computer system requirements for performing the simulation tasks as well as the time-sharing requirements. In addition, candidate computer configurations are provided which meet the requirements. The Applications Software is divided into ten major systems by engineering discipline. No attempt is made here to arrive at an optimum distribution by work package.

The following pictorial charts provide an overview of the systems and subsystems covered in this report and includes paragraph numbers for quick reference.

In most cases, the operational on-board subsystems have either not been developed or selected for use in the shuttle. This has necessitated using existing aerospace subsystems as "like-items" for the SCD. In all conceptual designs, the requirements of the real world systems as expected on 12/31/72 are met.

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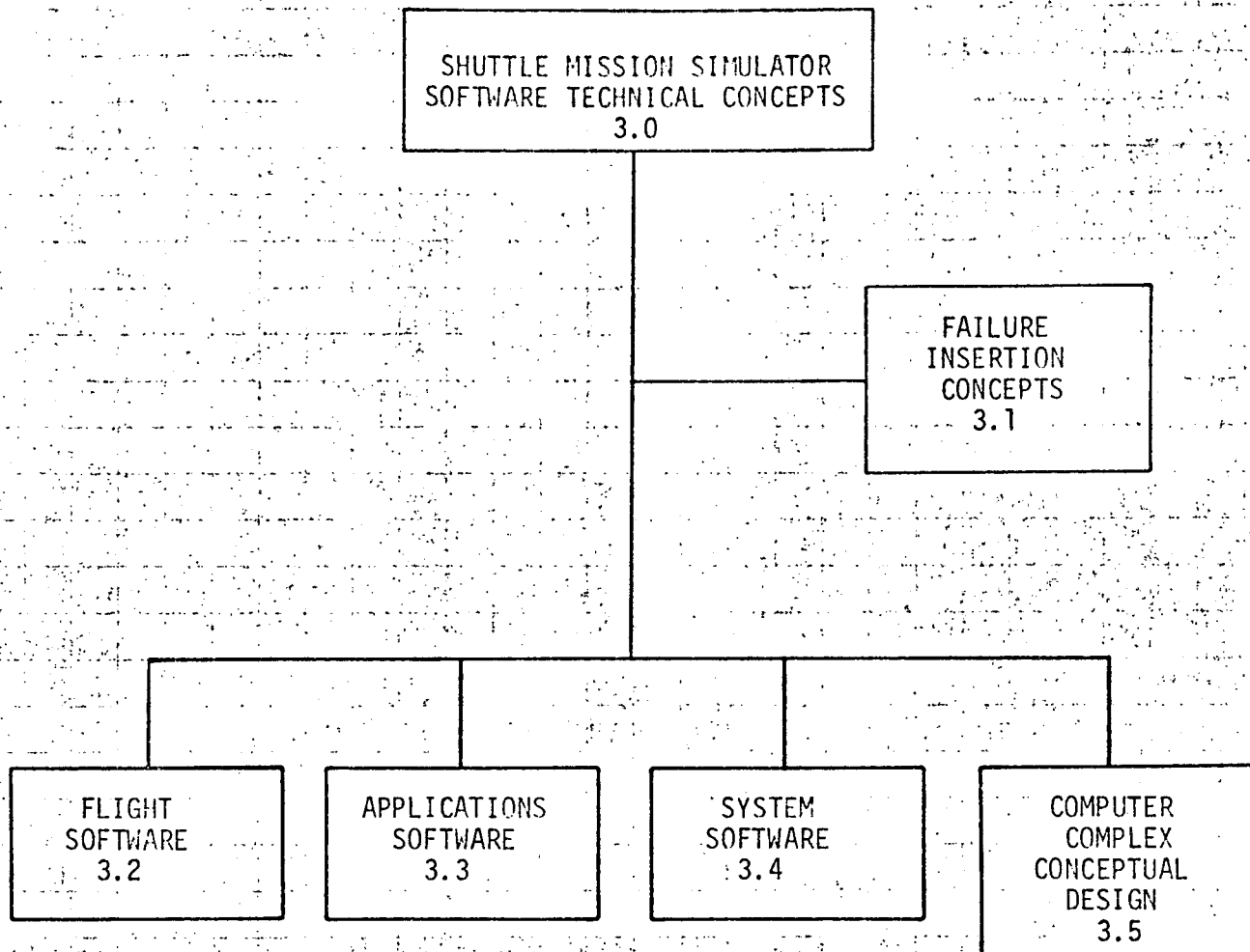


FIGURE 1-1

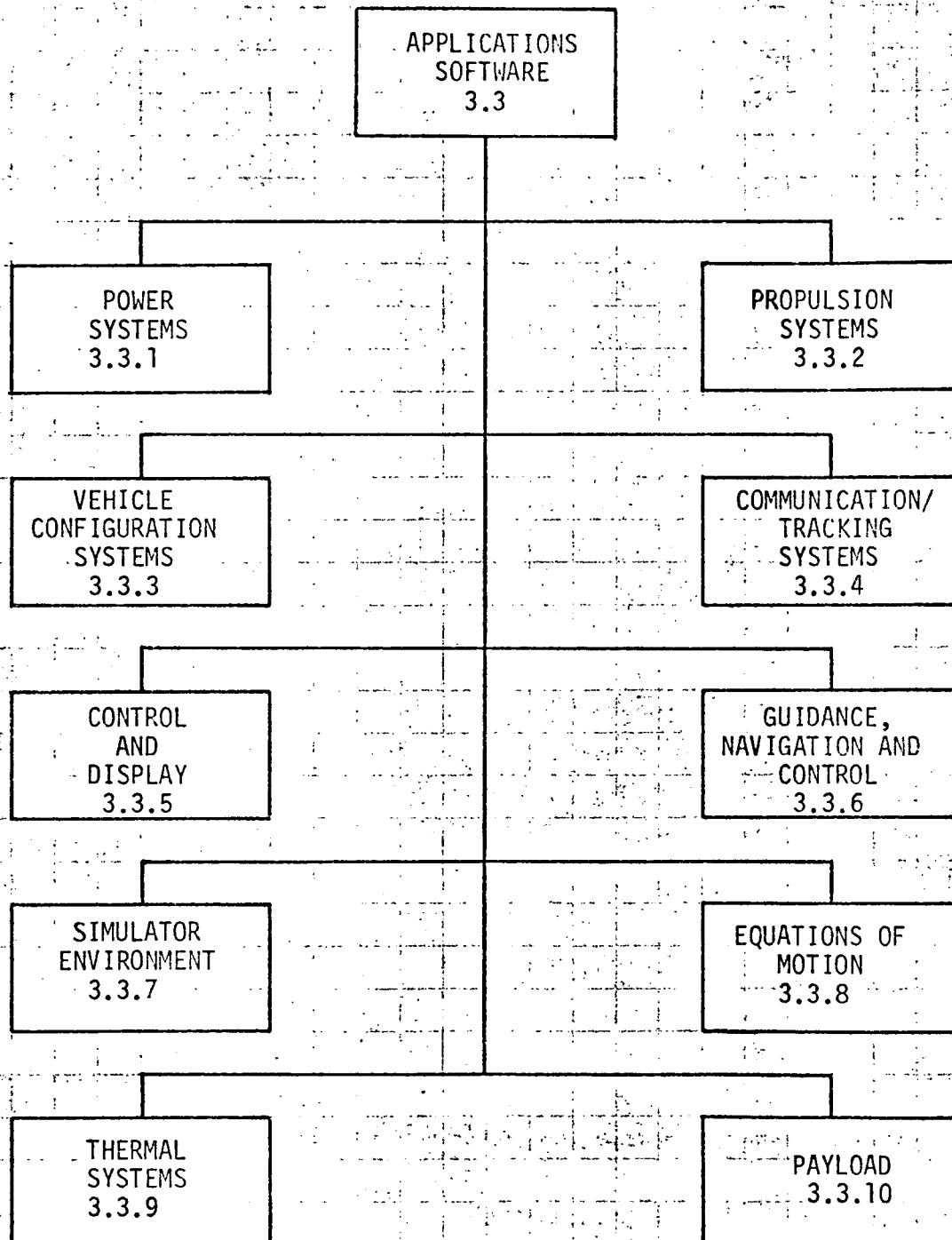


FIGURE 1-2

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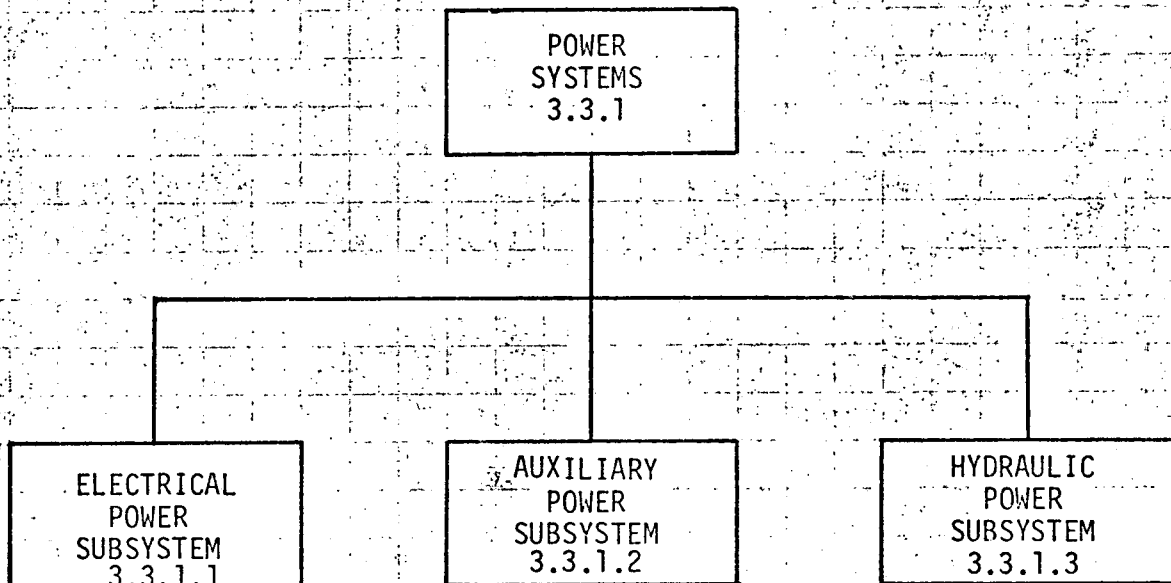


FIGURE 1-3

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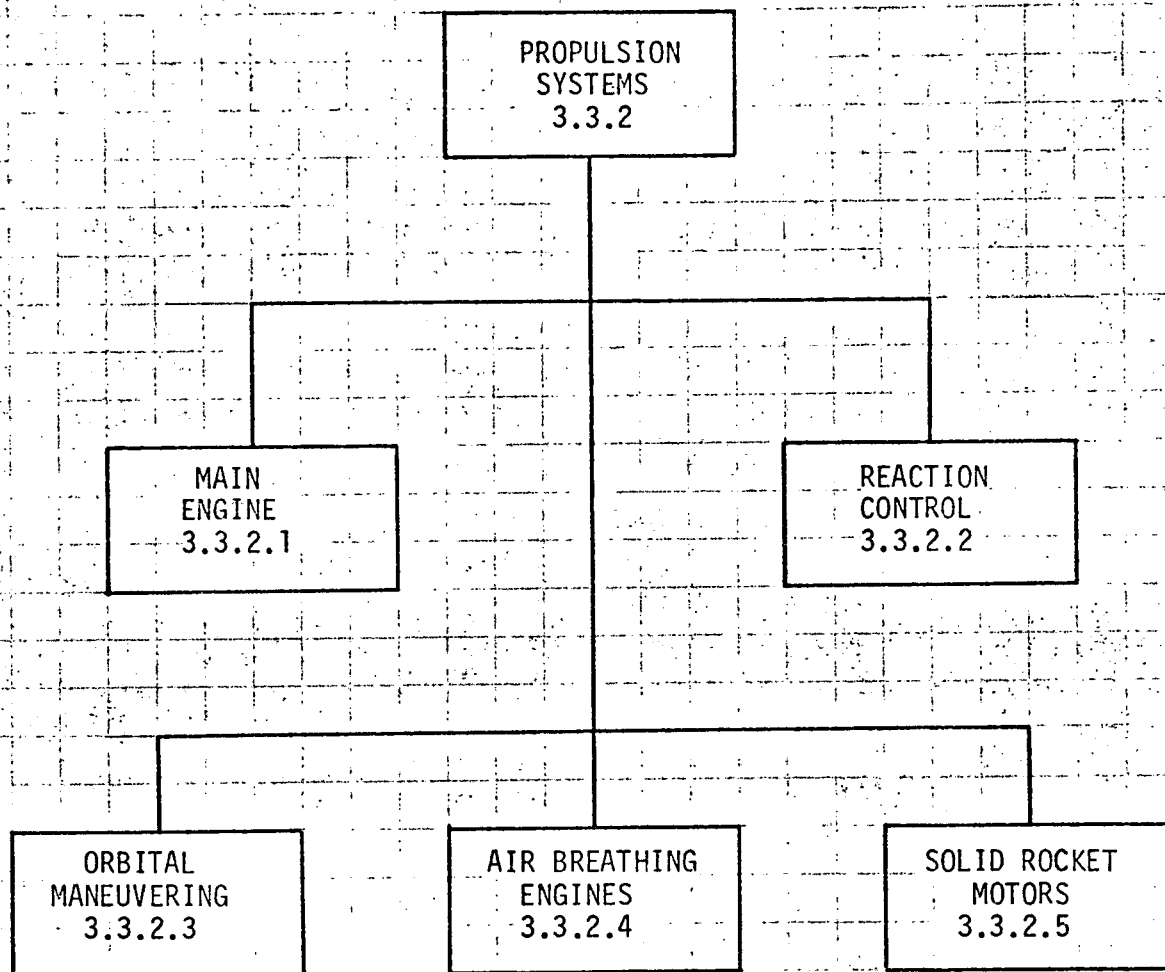


FIGURE 1-4

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VEHICLE
CONFIGURATION
SYSTEM
3.3.3

EXTERNAL TANK
SUBSYSTEM
3.3.3.1

LANDING GEAR
SUBSYSTEM
3.3.3.2

DOCKING
SUBSYSTEM
3.3.3.4

DRAG CHUTE
SUBSYSTEM
3.3.3.3

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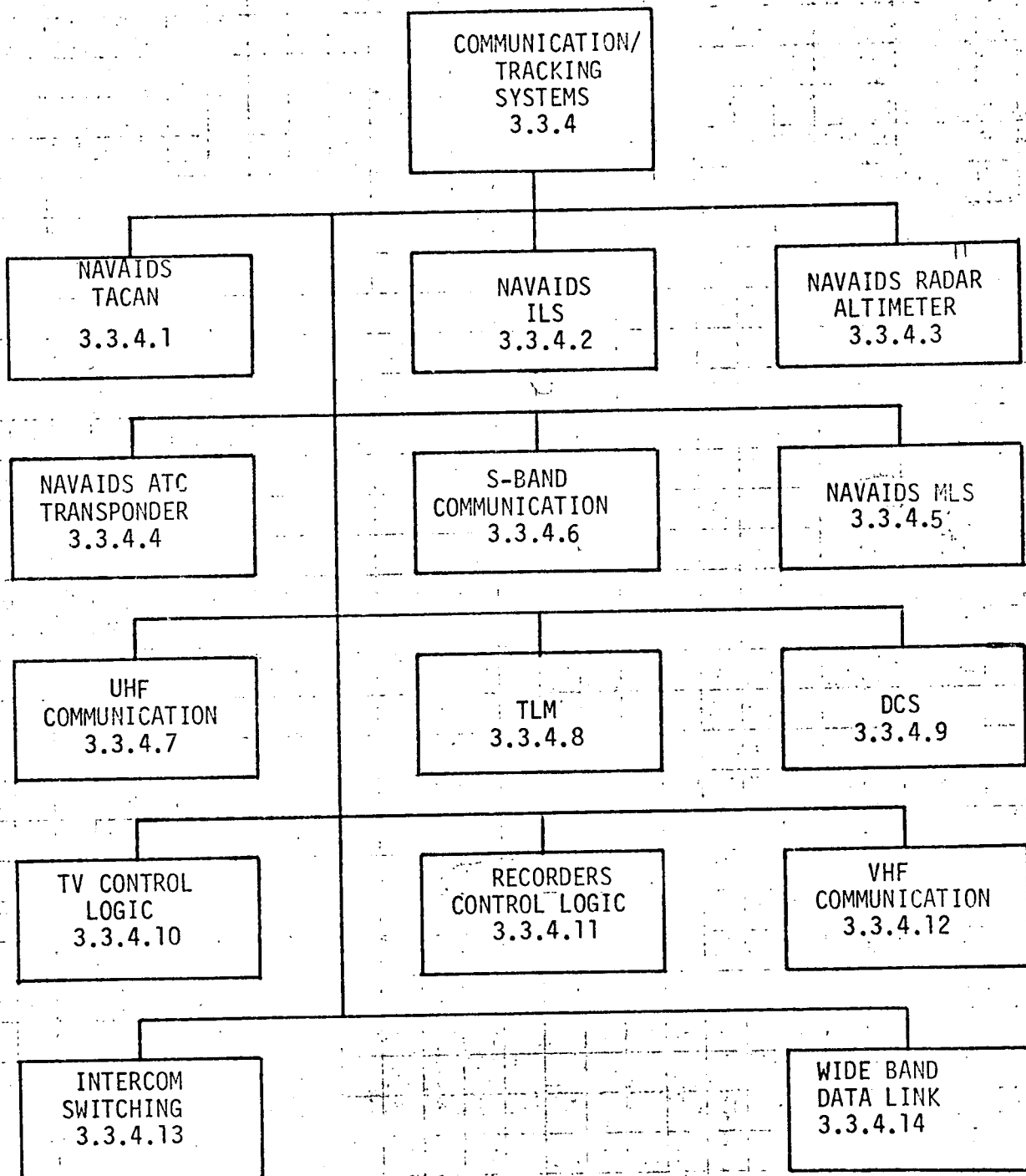


FIGURE 1-6

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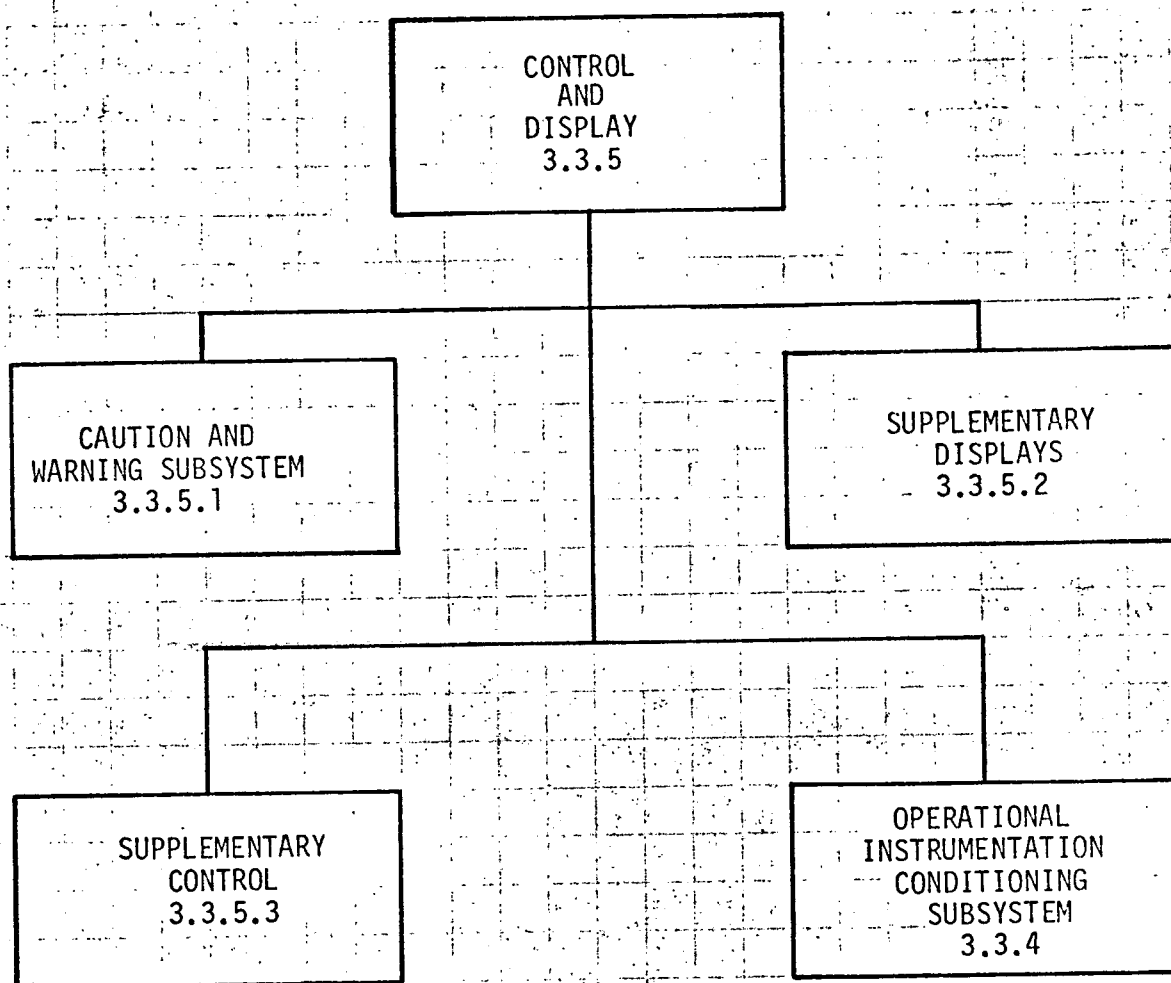


FIGURE 1-7

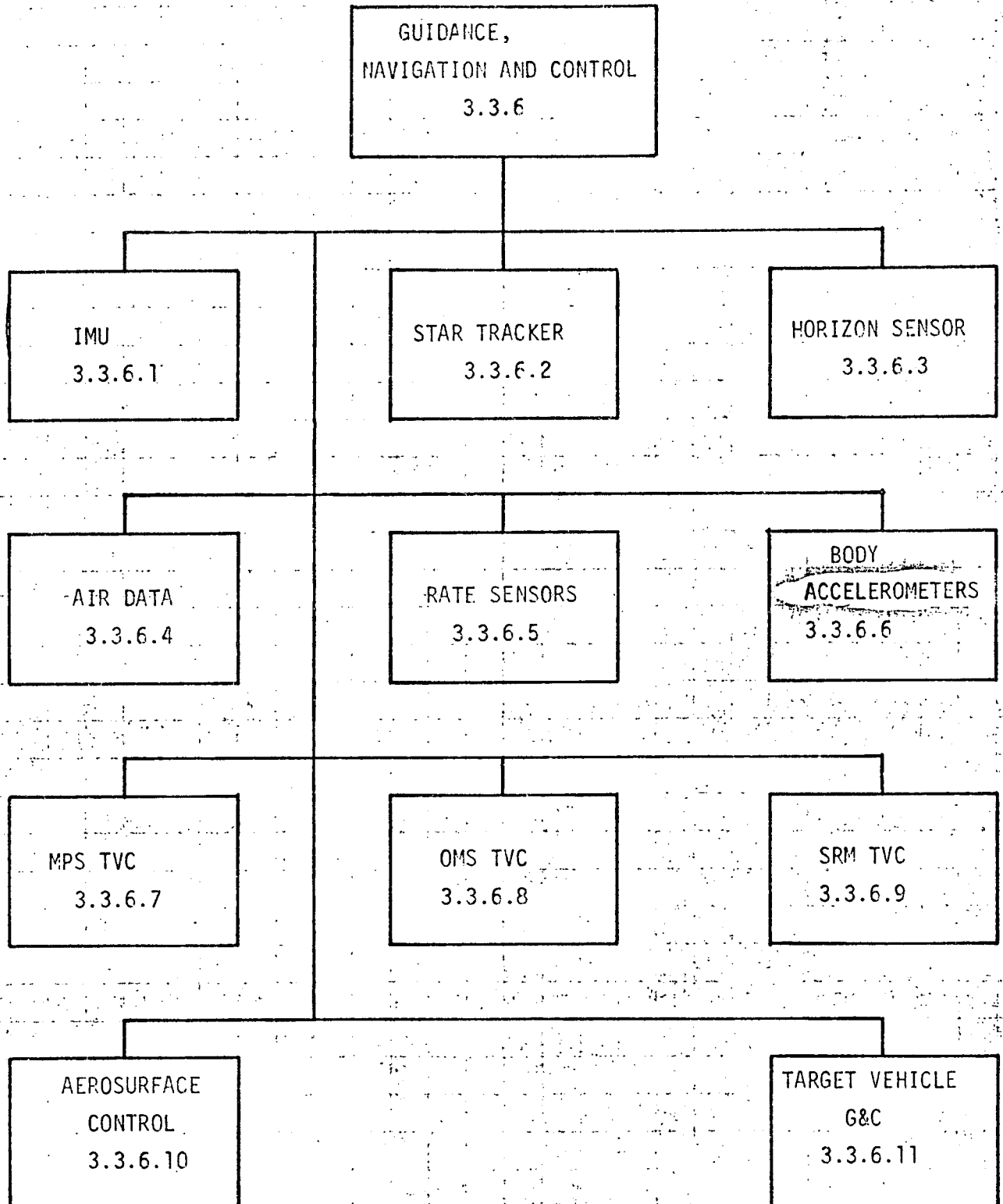


FIGURE 1-8

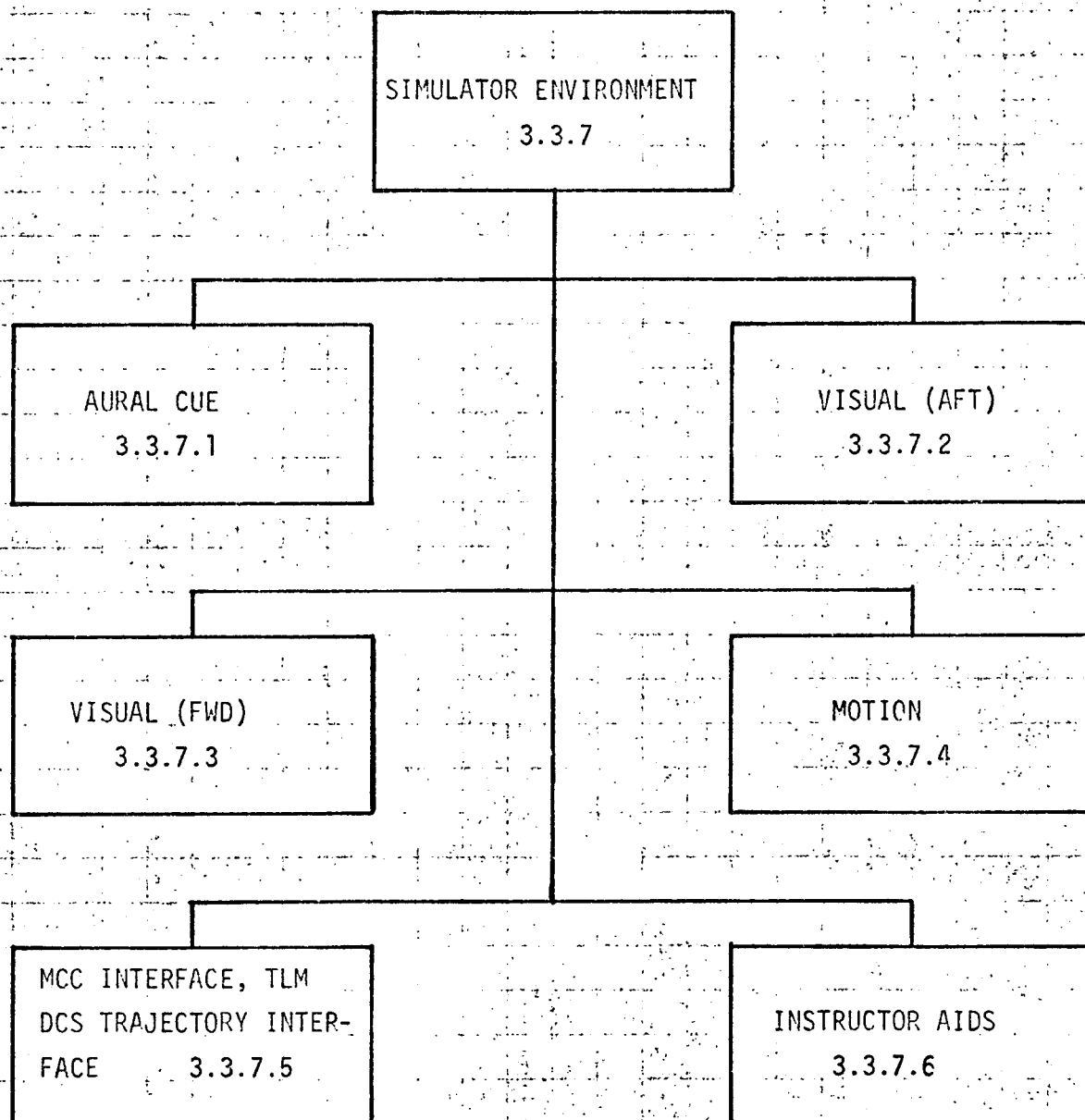


FIGURE 1-9

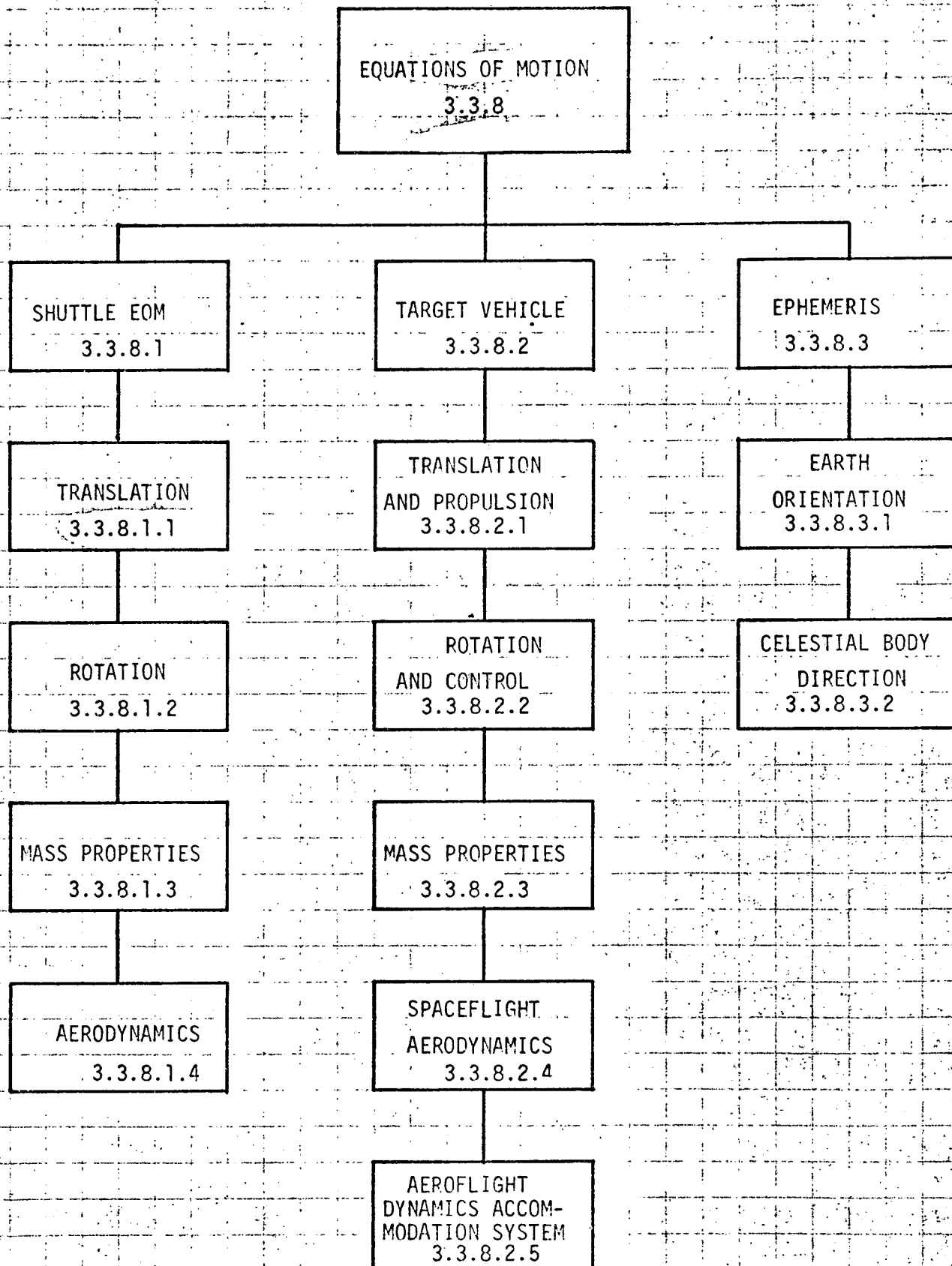


FIGURE 1-10

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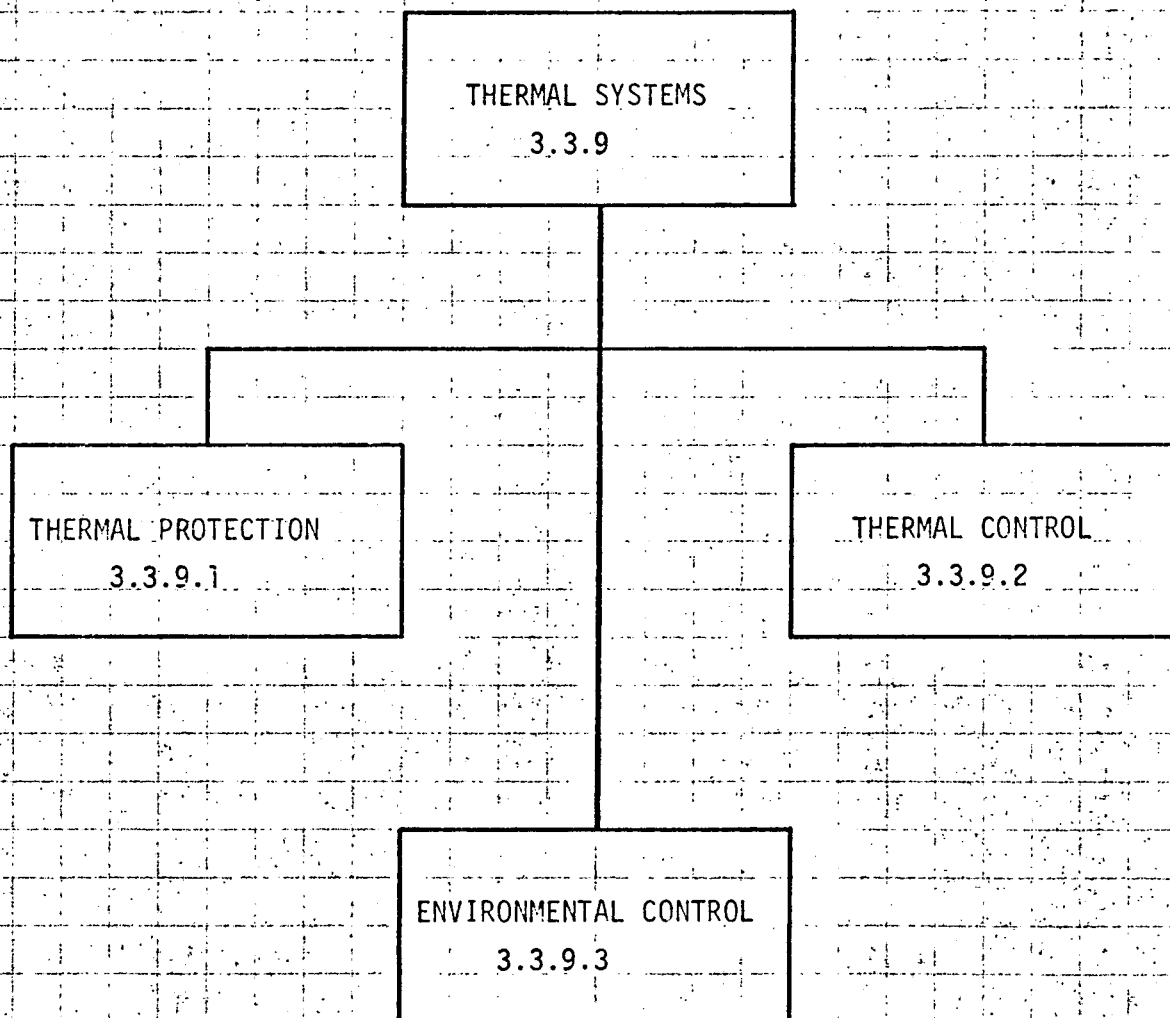


FIGURE 1-11

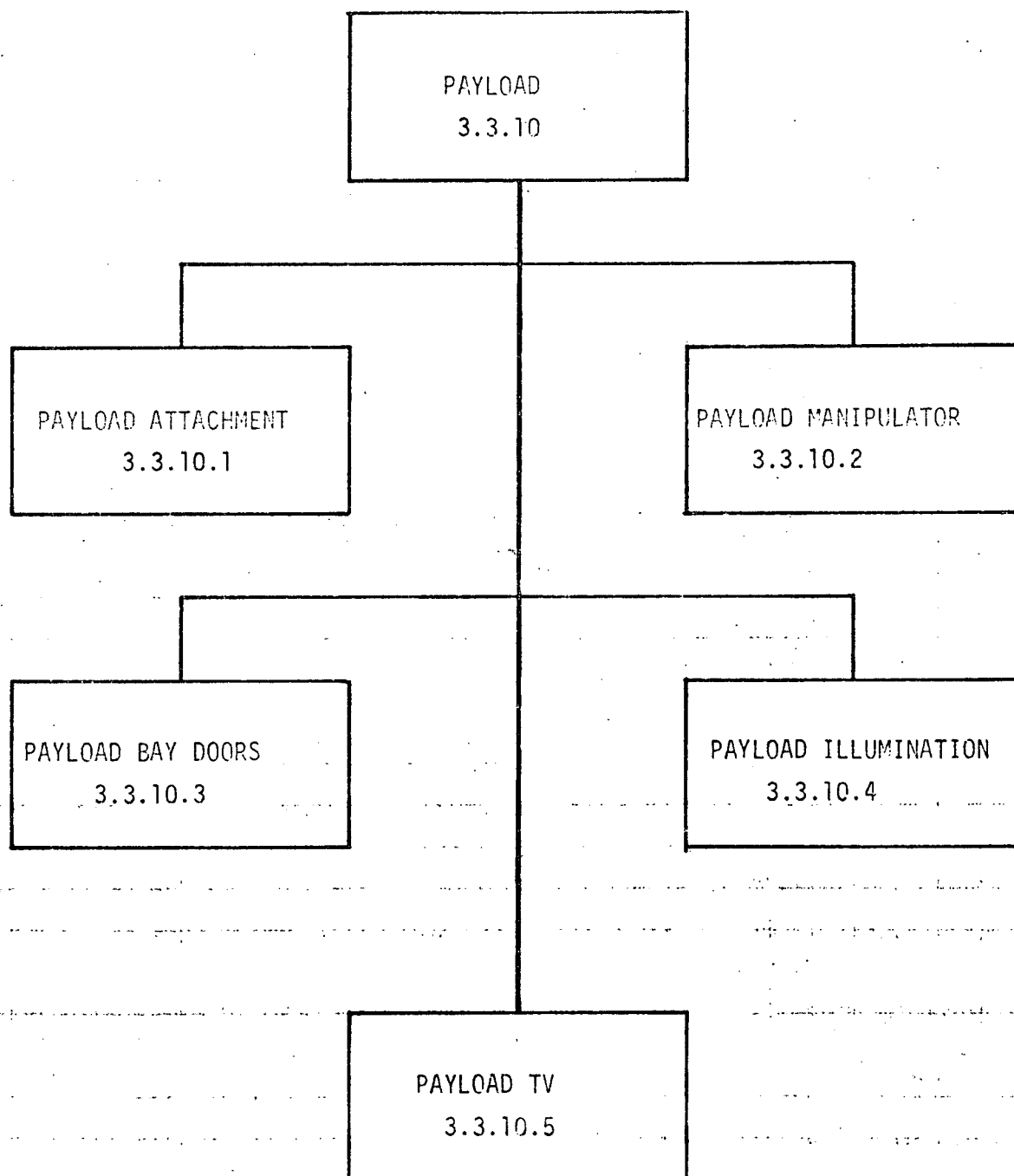


FIGURE 1-12

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SYS. S/W CONCEPTUAL DESIGN

3.4

SIM. CONTROL SOFTWARE

3.4.1

DATA MANAGEMENT SYS.

3.4.2

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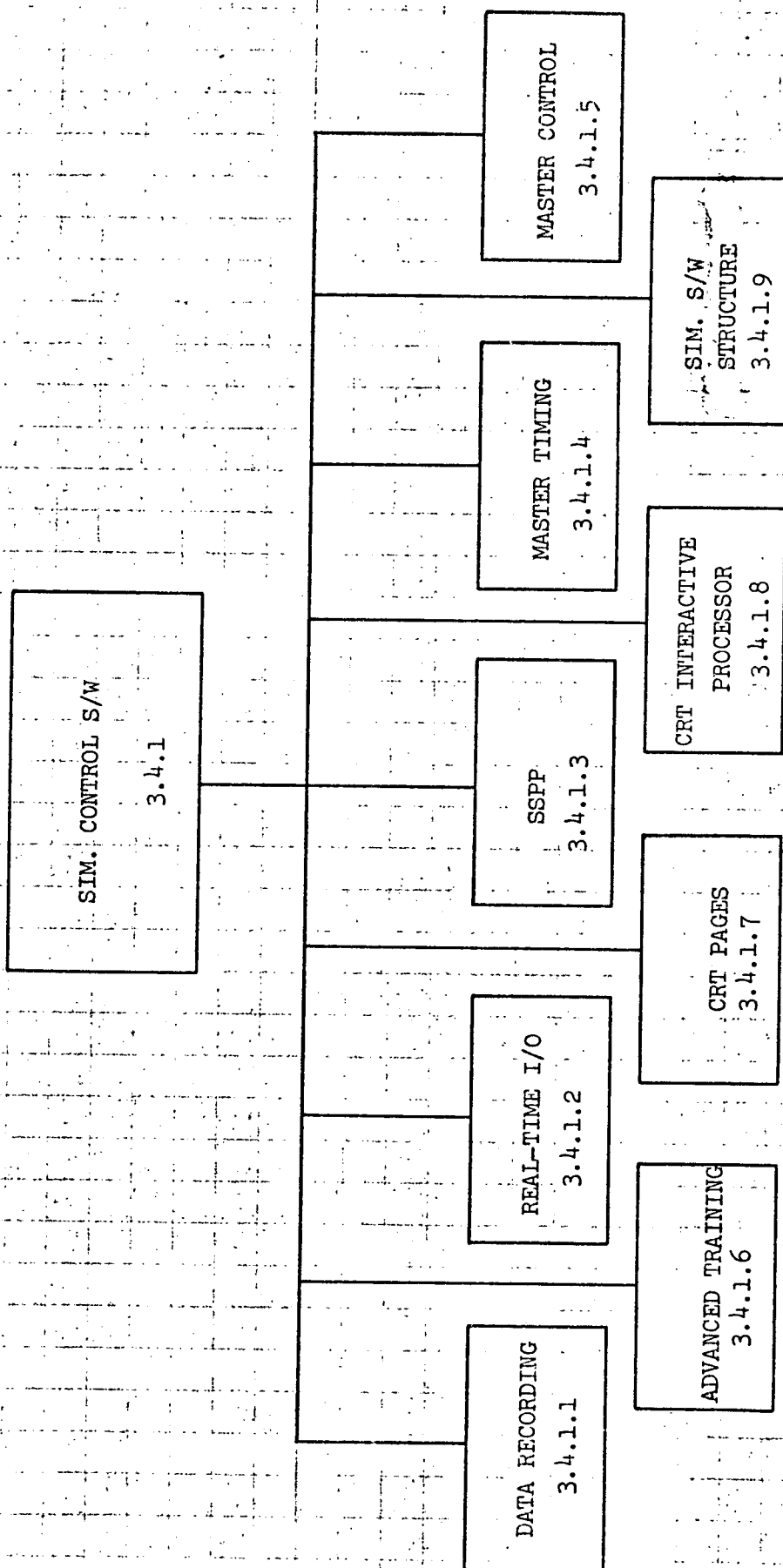
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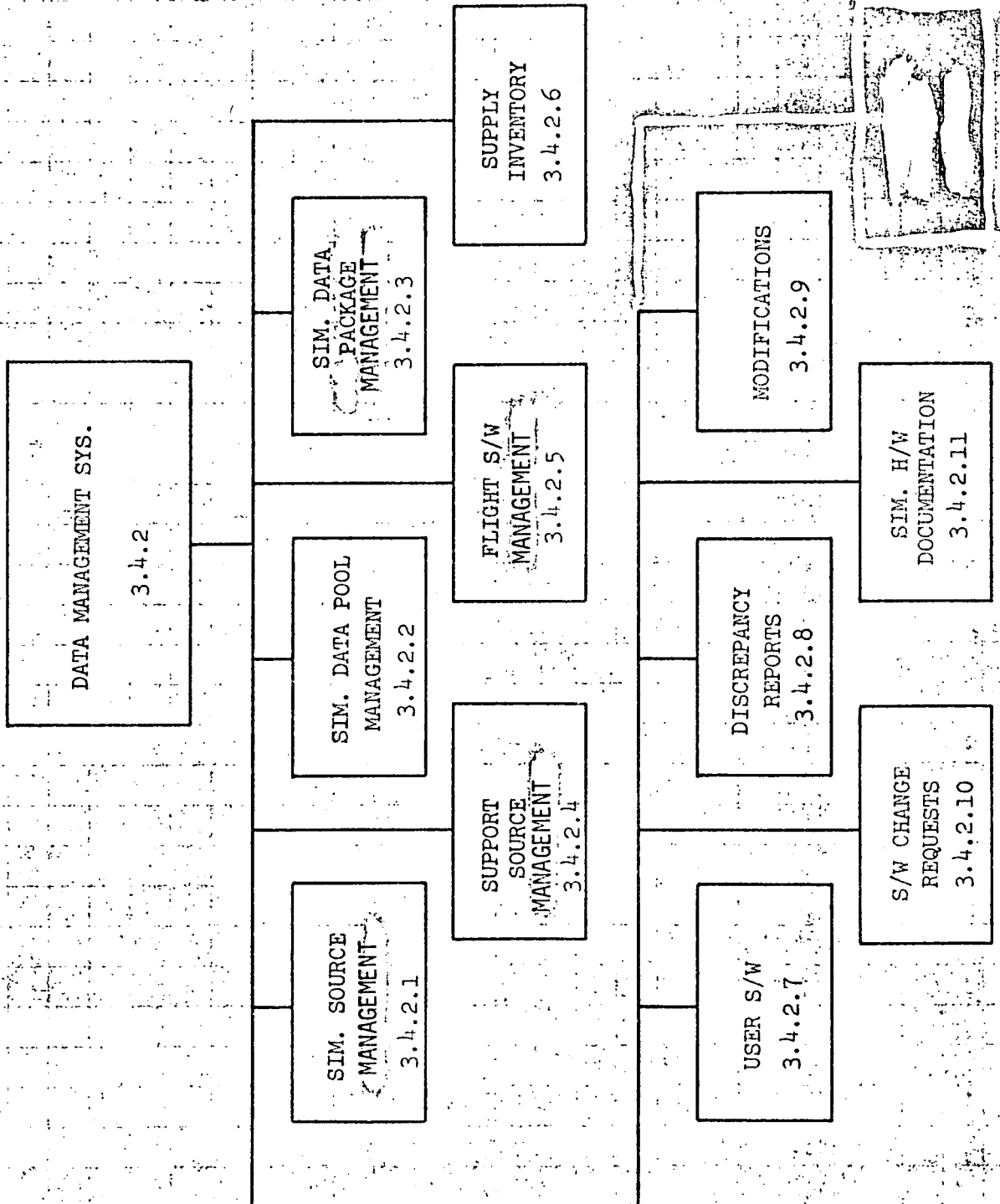
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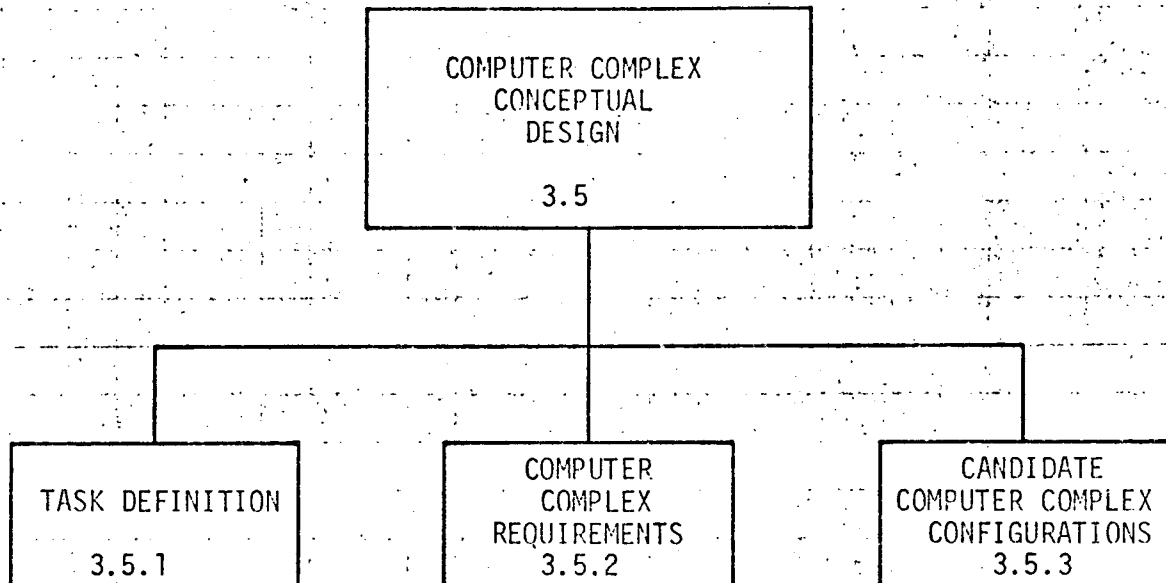
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TASK DEFINITION

3.5.1

SIMULATION
TASK
3.5.1.1

TIME-SHARING
TASK
3.5.1.2

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COMPUTER COMPLEX
REQUIREMENTS

3.5.2

HOST COMPUTER
SYSTEM
REQUIREMENTS
3.5.2.1

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REQUIREMENTS
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ON-LINE
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REQUIREMENTS
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OPERATING
SYSTEM
REQUIREMENTS
3.5.2.4

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CANDIDATE
COMPUTER COMPLEX
CONFIGURATIONS
3.5.3

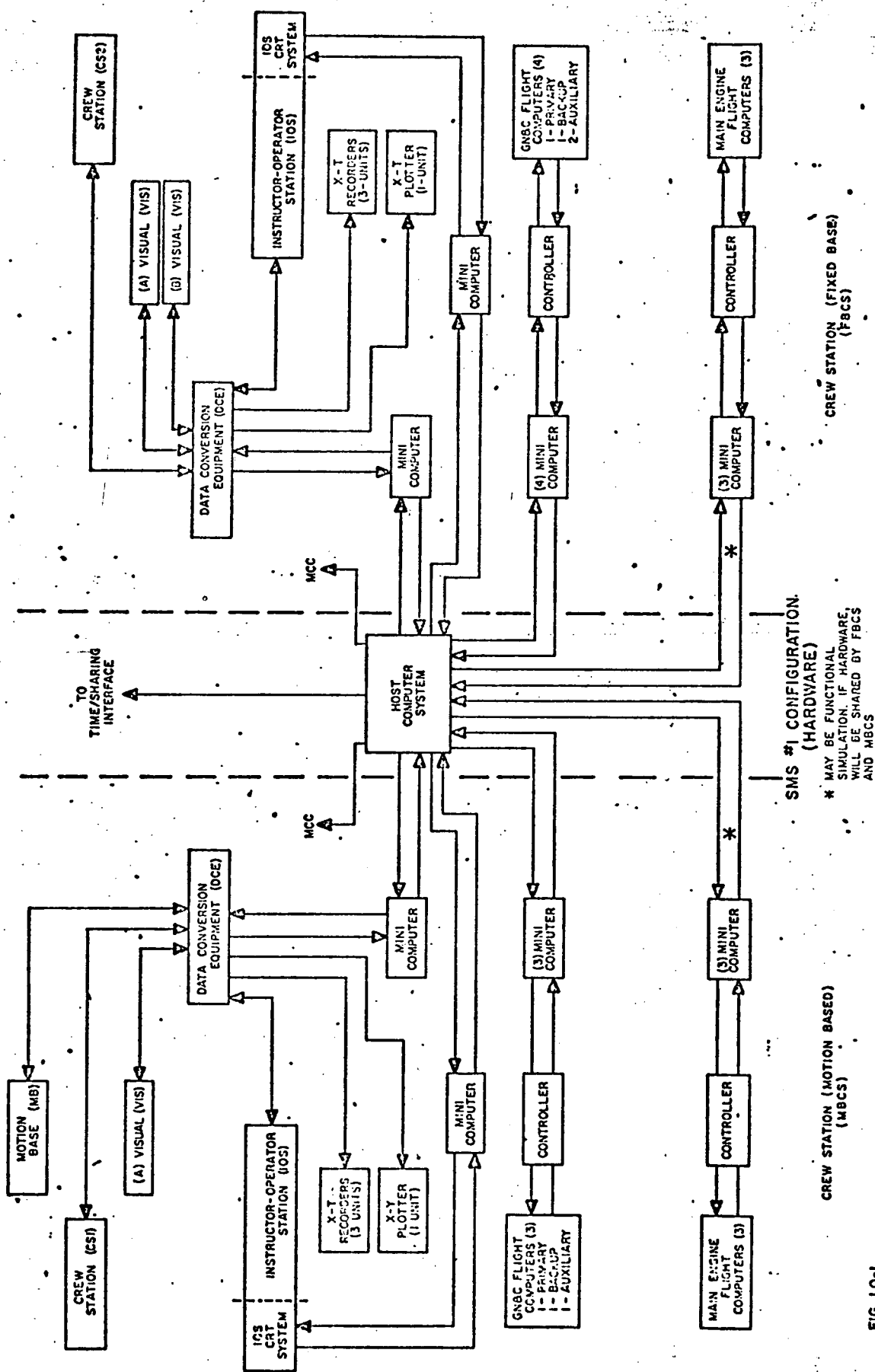


FIG. 10-1

2.0 General Description

2.1 Trainer Configurations

The trainer configuration as considered by the SCD is shown in Figure 1.0-1. It consists of the Motion Base Crew Station (MBCS), the Fixed Base Crew Station (FBCS), the Instructor Operator Station, (IOS), and the Computer Complex as major hardware components. Some of the features of these units are:

MBCS:

- 4-man seating in crew station
- 6 DOF + Tilt Motion System
- Fully operational simulation of Commander station
- Fully operational simulation of Pilot Station
- Full forward windows visual systems
- No aft windows visual systems
- No payload
- No payload manipulators
- Mission Specialist seat only
- Payload Specialist seat only
- No lower crew compartment

FBCS:

- 4-man crew station
- No motion system
- Five fully operational stations simulated
- Full payload training capability
- Full payload manipulator training capability

IOS:(MBCS)

- 2 CDR station CRT's
- 2 Pilot station CRT's
- 1 CDR/Pilot-shared CRT
- 1 Mobile TM CRT/cabinet (shared with FBCS)
- Monitor CRT's for all on-board CRT's
- 3 X-T recorders
- 1 X-Y recorder
- Instructor Portable IOS at Payload or Mission Specialist Stations
- 2 Visual monitor CRT's

(FBCS)

- 2 CDR station CRT's
- 2 Pilot station CRT's
- 1 CDR/Pilot-shared CRT
- 1 Mobile TM CRT/cabinet (shared with MBCS)
- 1 Orbit station CRT
- Mission Specialist CRT
- Payload Specialist CRT
- TV Repeaters for Mission/Payload Specialists
- Monitors for all on-board CRT's
- Orbit Station visual monitor
- 2 CDR/Pilot visual monitors
- 3 X-T recorders
- 1 X-Y recorder

COMPUTER COMPLEX:

• Host Computer System

MIP rate

Word length

Addressable storage

Input/Output transfer rates

• Time Sharing

Batch stations

Interactive terminals

• On-Line Peripherals

Card reader/punch

Line printers

Mass storage

Magnetic tape

• Candidate configurations

• DCE

Mini-computer linkage

Devices

Type

Number of channels

2.2 Training Modes

For purposes of the SCD, the trainer is assumed to have the capability of the following training modes:

MBCS only: Prelaunch (Liftoff minus 10 minutes/to liftoff)

Launch (to External tank deorbit)

Launch Abort

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Deorbit and Entry

Approach and Landing

Ferry

Orbital (CDR/Pilot part tasks only)

FBCS only: Full mission exclusive of motion cues

MCC Integrated: MBCS or FBCS

2.3 Time Sharing

The capability for background time sharing computer work is considered for all modes of utilization of the simulator complex. Remote terminals will provide management and engineering processing capabilities.

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3.0 Technical Concepts

3.1 Failure Insertion Concepts

3.1.1 System Design Techniques

In many cases of simulation, the mathematical model malfunctions are added as an afterthought in the design process. Where the system has redundant components or paths, repetitive program loops are used to reduce the core requirement of the executable program. Implementation of malfunctions into these component models requires that a comparative study be made to determine the method for the least computer core and executable time requirement. In all cases it will be found that a compromise must be made between time and core. In the following four example cases, the various methods of implementation within a Do-Loop of 10 are shown with a time and core impact. In these examples a computer time of 1.5 μ sec per instruction is assumed. Cases V and VI show the trade-off as was made in Skylab EPS simulation.

For purposes of clarification, the term multiple malfunction means that one data base word is used to direct a change in computational processing such that more than one segment or component may be addressed by changing of the code letter or number stored in the data base location. Cases V and VI show an example of use of "multiple malfunctions" to save time and core.

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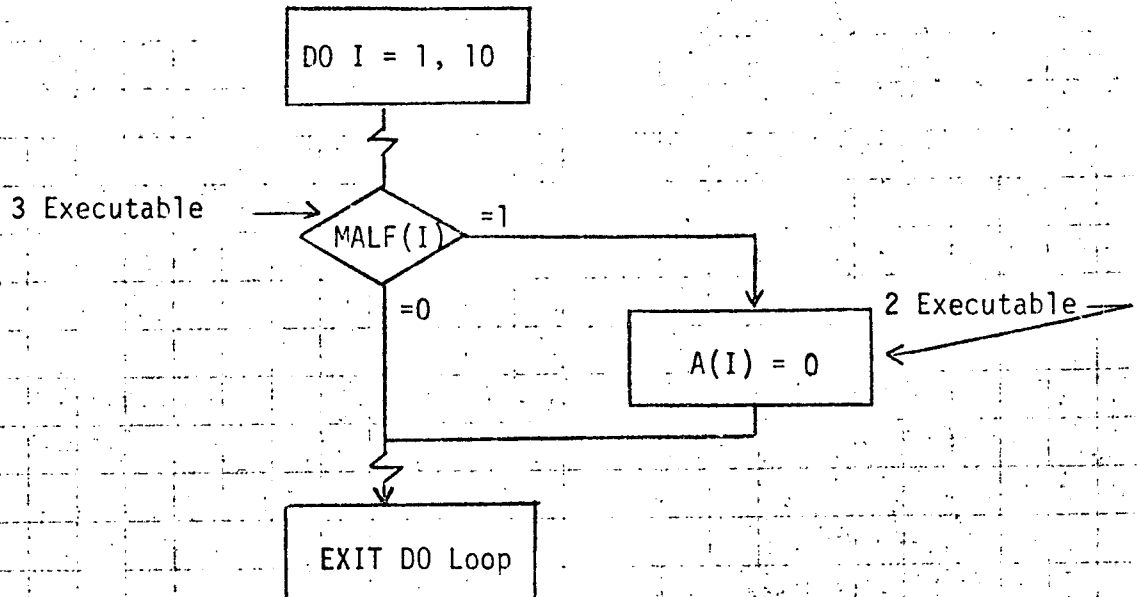
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CASE I: 10 Discrete Malfunctions Used Inside DO Loops

Core Summary:	Storage	Executable	Total	Bytes
	10	5	15	60

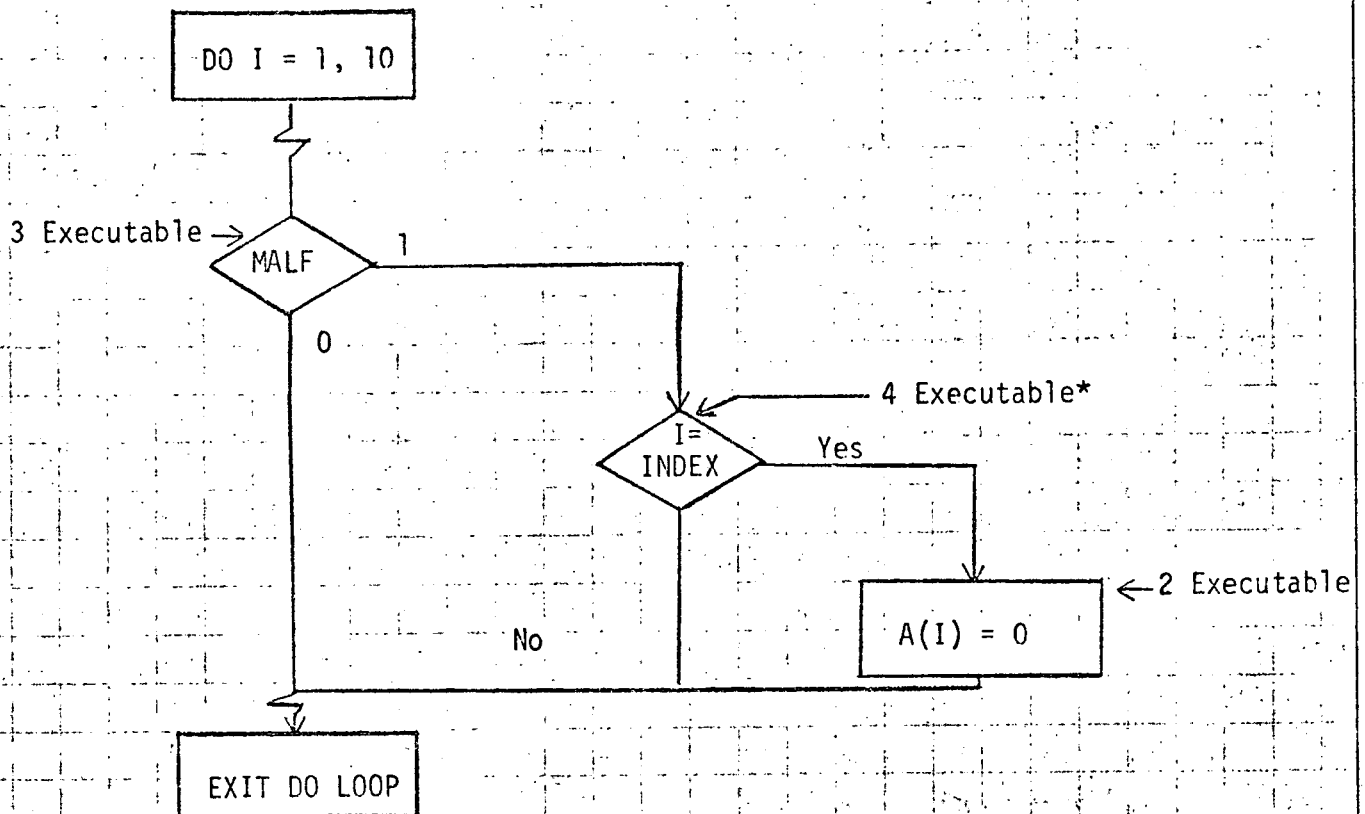
Time Summary:	Best:	Worst:	Nominal:
	$3 \times 10 \times 1.5 = 45 \mu S$	$5 \times 10 \times 1.5 = 75 \mu S$	$3 \times 10 \times 1.5 = 45 \mu S$

Advantages:

- 1) All 10 malfunctions can be entered simultaneously.
- 2) Low execution time.
- 3) Easy to enter and remove via CRT.

Disadvantages: 1) High core requirement.

CASE II: One Discrete Malfunction, one malfunction index used to indicate which one of the 10 elements should be malfunctioned. All inside DO Loop.



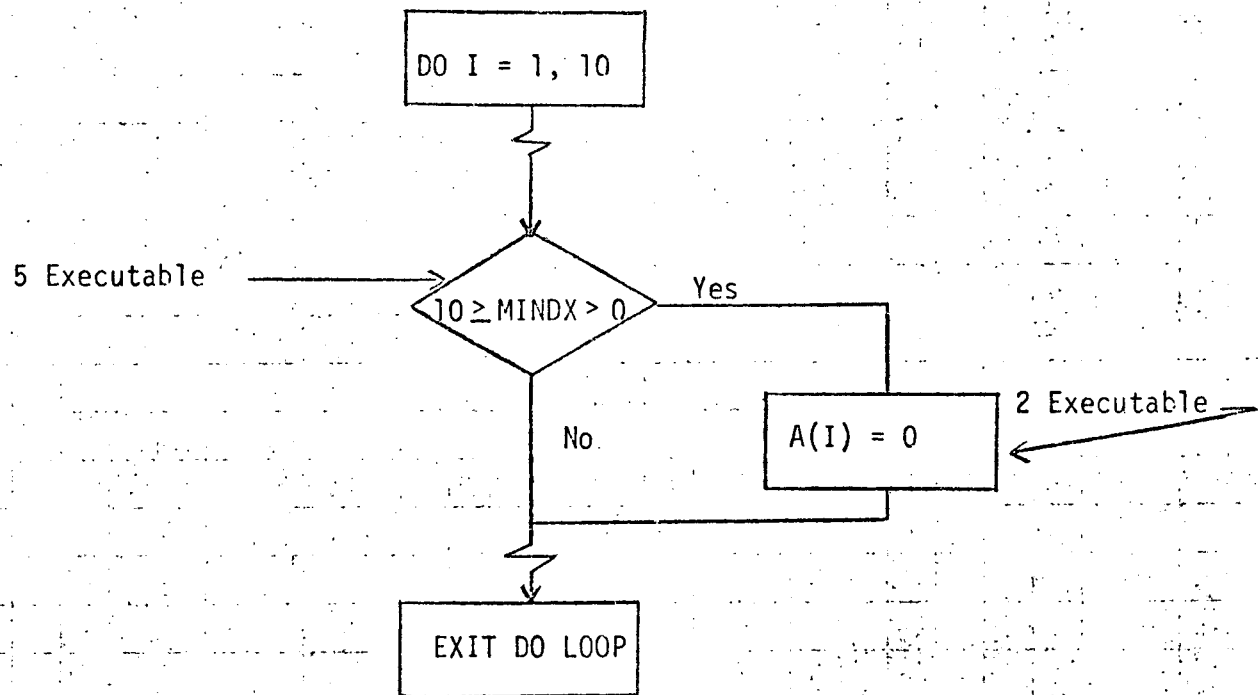
Core Summary:	Storage	Executable	Total	Bytes
	2	9	11	44

Time Summary: Best: $3 \times 10 \times 1.5 = 45 \mu S$
 Worst: $9 \times 10 \times 1.5 = 135 \mu S$
 In $I = \text{Index}$: $9 \times 10 \times 1.5 = 135 \mu S$
 In $I \neq \text{Index}$: $7 \times 10 \times 1.5 = 105 \mu S$

Advantages: 1) Lower Core Requirement.
 2) Low time when malfunction not in.

Disadvantages: 1) High time when malfunction in.
 2) Hard to enter and clear.
 3) Only one malfunction may be used at one time.

CASE III: One malfunction integer location to indicate malfunction entered and specific element affected. All inside DO Loop.



Core Summary:	<u>Storage</u>	<u>Executable</u>	<u>Total</u>	<u>Bytes</u>
	1	7	8	32

Time Summary:	Best	Worst:	Nominal:
	5 X 10 X 1.5 = 75 μ S	7 X 10 X 1.5 = 105 μ S	5 X 10 X 1.5 = 75 μ S

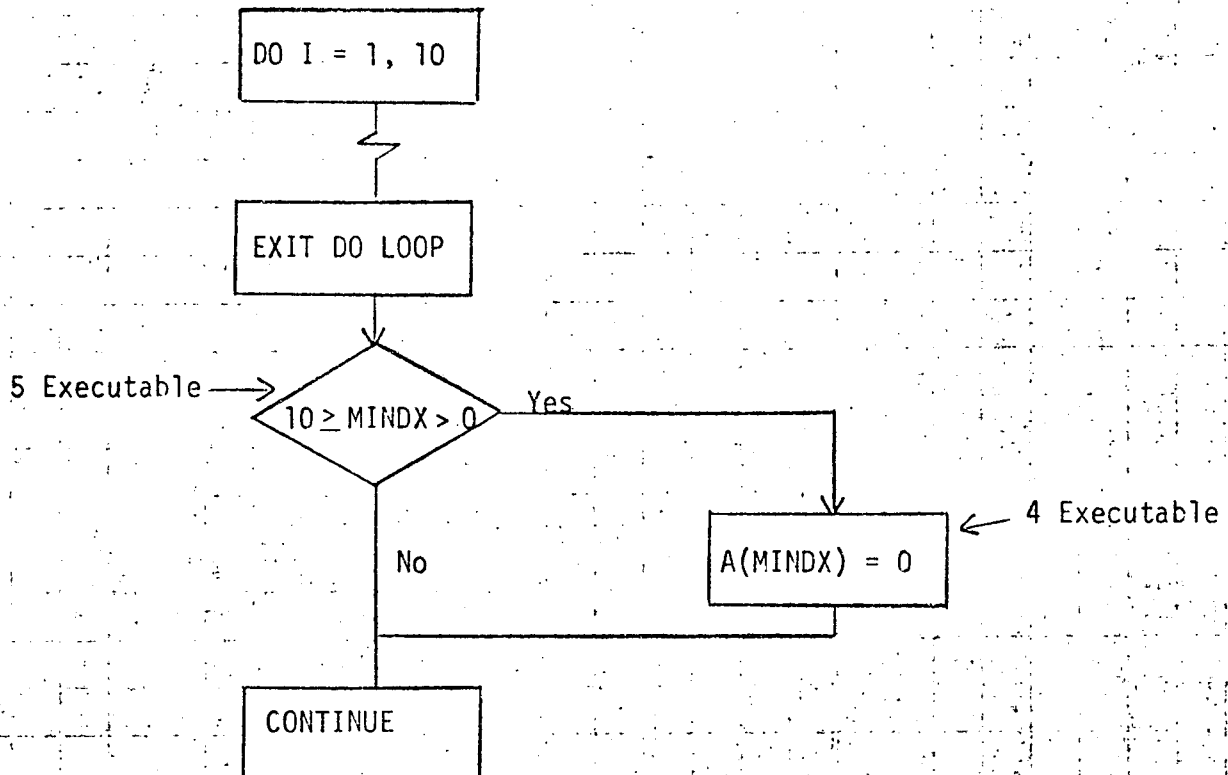
Advantages:

- 1) Low Core Requirement.
- 2) Easy to enter malfunction.

Disadvantages:

- 1) High time requirement for all paths.
- 2) Only one malfunction entered at one time.

CASE IV: One malfunction integer location to indicate malfunction entered and specific element affected. Malfunction programmed outside the DO Loop.



Core Summary:	Storage	Executable	Total	Bytes
	1	9	10	40

Time Summary:

Best: 5 X 1 X 1.5 = 7.5 μ S

Worst: 9 X 1 X 1.5 = 13.5 μ S

Nominal: 5 X 1 X 1.5 = 7.5 μ S

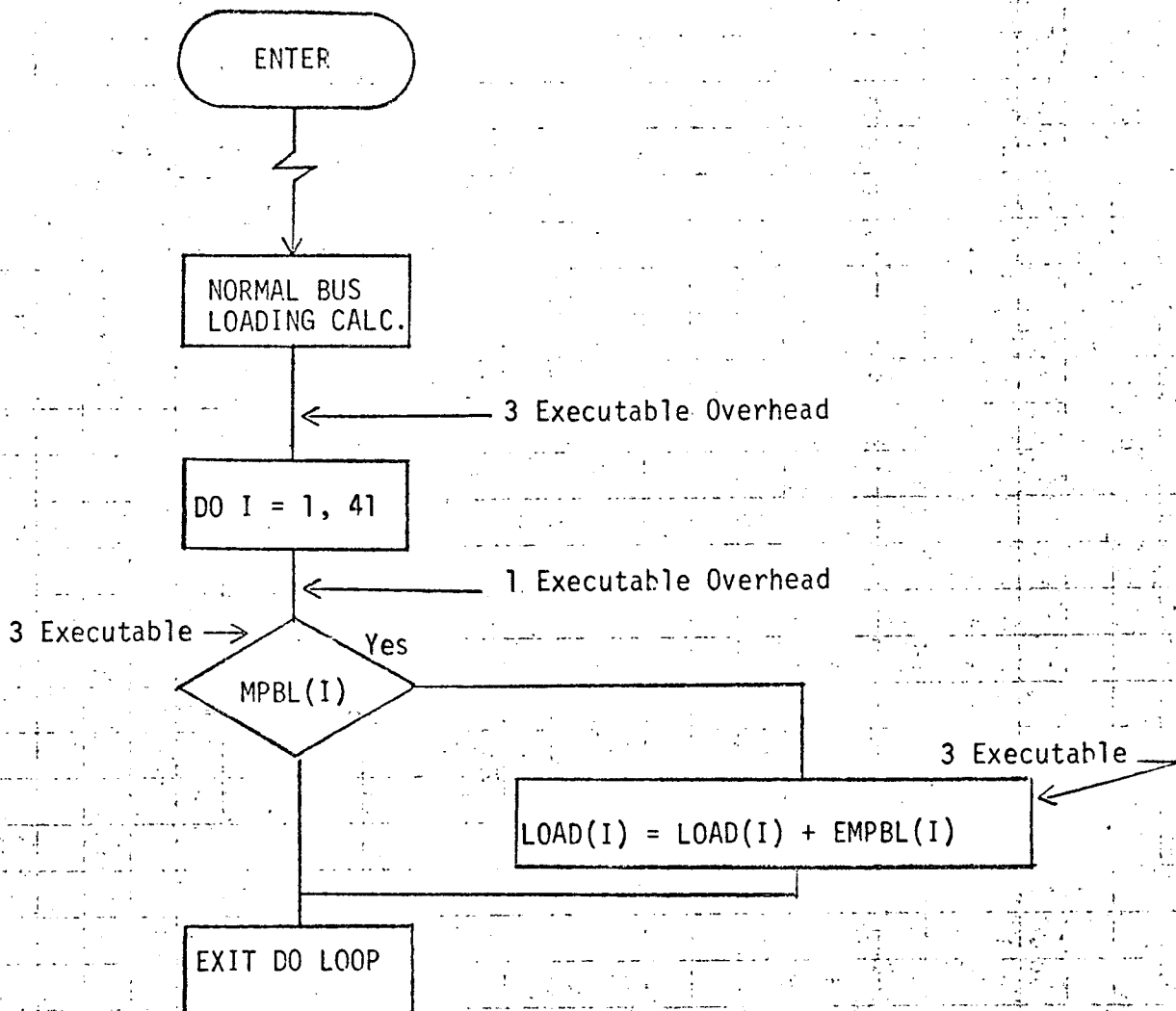
Advantages:

- 1) Low Core Requirement
- 2) Low Time Requirement
- 3) Easy to enter and remove

Disadvantages:

- 1) Only one element may be malfunctioned at a time.
- 2) Requires that Do Loop has ended or that additional time and core is required to do this.

CASE V: EPS Power Bus Loading Bus Overload Malfunctions. Forty-one Discrete Variable Malfunctions.



Core Summary:	Storage	Executable	Total	Bytes
	82	10	92	368

Time Summary:

Best:	$[3 + (4)(41)] \times 1.5 = 250.5 \mu S$
Worst:	$[3 + (7)(41)] \times 1.5 = 435.0 \mu S$
Nominal:	$[3 + (4)(41)] \times 1.5 = 250.5 \mu S$

Advantages:

- 1) All 41 can be entered at one time.
- 2) Easy to enter and remove.

Disadvantages:

- 1) High Core Requirement
- 2) High Time Requirement

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Core Summary:	<u>Storage</u>	<u>Executable</u>	<u>Total</u>	<u>Bytes</u>
	10	50	60	240

Time Summary: Best: $25 \times 1 \times 1.5 = 37.5 \mu S$
Worst: $50 \times 1 \times 1.5 = 7.5 \mu S$
Nominal: $25 \times 1 \times 1.5 = 37.5 \mu S$

Advantages: 1) Lower Core (128 Bytes saved)
2) Lower Time (360 μS worst case, 213 μS best case)

Disadvantages: 1) Only 5 buses can be malfunctioned at one time
(however, this meets the instructor's requirements).

3.1.2 Techniques of Manual Insertion

Malfunctions may be manually entered into the simulation problem in one of two ways. The first method requires that the malfunction page be selected, an available line on the page be selected, the malfunction symbol entered along with the value to be inserted into the malfunction term. Malfunctions may also be entered into the simulation problem by using the CRT keyboard. By using procedures similar to "Look and Enter" (i.e., depression of function key, entry of symbolic name, entry of value), malfunctions may be entered without selecting the malfunction page.

3.1.3 Malfunction Display Methods

Active malfunctions in the simulator may be viewed at any time by one of two methods. The first is by selecting the malfunction page. The second method involves selecting the 'active malfunction and tripped circuit breaker' page. Both pages will present a list of all current active malfunctions, and their current value.

3.1.4 Pre-Programmed Malfunctions

The insertion and control of simulated malfunctions of equipment or of variable vehicle flight conditions has required the NASA instructor to concentrate his attention on performing tasks which could be relegated to the computer. Having the computer pre-programmed to insert and/or change operating conditions will free the instructor to concentrate his efforts on those tasks the computer cannot handle such as trainee response and performance. The insertion of malfunctions through the use of a dedicated CRT page entry, similar to the existing Skylab simulation malfunction technique, may be accomplished at any time in real time mode. The automated

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technique may be used to insert, display, or delete any malfunction or data base parameter by the use of pre-programmed software modules. The modules may be activated or deactivated by the instructor in real time. Display devices (CRT digital, graphics, X-T recorders, X-Y recorders) and audio cues may be activated by the use of the pre-programmed modules.

Use of this technique will allow the instructor to preplan his malfunction study program and to present identical training situations to all students. The technique also frees the instructor from having to do repetitious keyboard entry which, through human error, could lead to destruction of the training plan and computer schedule.

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3.2 Flight Software Conceptual Design

In order to maintain the integrity of the discussion of flight hardware/software, the flight software conceptual design is covered in the Hardware Conceptual Design report. Interfacing systems are covered in this report under Main Engines and Guidance, Navigation and Control.

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3.3 Applications Software Conceptual Design

3.3.1 Power Systems

3.3.1.1 Electrical Power Subsystem

The Electrical Power Subsystem may be generally divided into six problem areas requiring math models. These are power interface, switching logic, bus loading, power generation and storage, power distribution, and control and display. For the shuttle vehicle there are three types of electrical power having distinct requirements for simulation. These are the DC subsystem, the single phase AC subsystem, and the three phase AC subsystem. Each of these subsystems interface with the others through electrical loads or by providing power sources. The concept presented here describes the subsystems separately with interfacing parameters between subsystems.

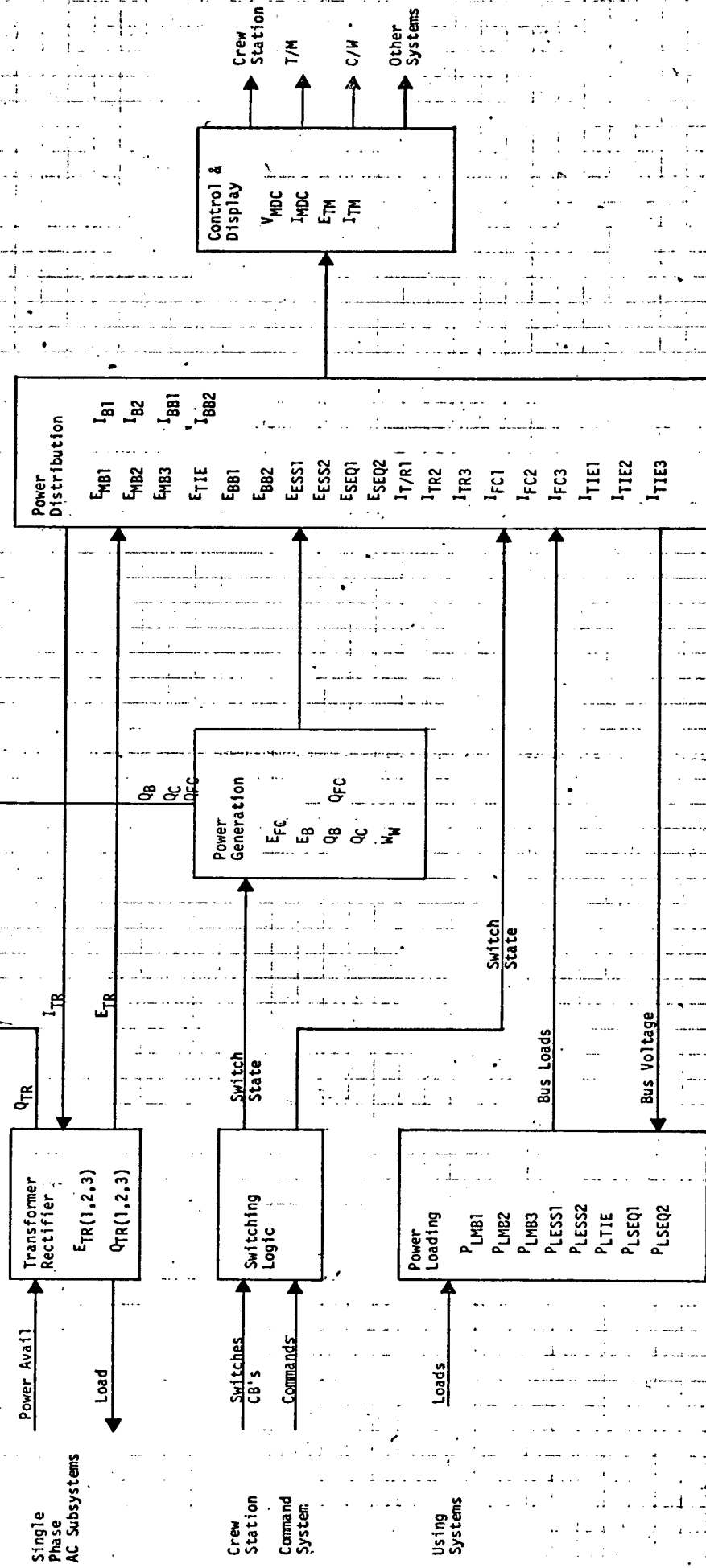
Figure 3.3.1.1.1 shows the proposed groups of equations required for the DC subsystem network. The DC subsystem has fuel cells, batteries, and transformer-rectifiers supplying power to three main DC buses, two battery buses, two essential control buses, and two sequencer buses. Because of malfunction consideration, the tie bus must also be considered as a load bus.

The transformer-rectifier equations provide the output voltage from each unit as a function of the electrical load current. A power available boolean will be made available by the single phase AC subsystem for each transformer-rectifier and, in turn, each transformer-rectifier will calculate electrical loads for the single phase AC subsystem. Load sharing will be accomplished by varying the T-R output voltage as a function of the electrical load. Curve fits to test data will be used for this function. Heat generated by the T-R unit will be calculated for the ECS Subsystem and ECS will calculate the unit temperature.

(1) T-R Output voltage

$$E_{TR} = f(I_{TR}) \text{ current and temperature limited function.}$$

3.3.1.1.1 DC POWER SUBSYSTEM



(2) T-R Heat generated

$$Q_{TR} = f(E_{TR}, I_{TR}, \text{Eff})$$

The power loading equations provide summations of all electrical loads on the DC buses. Individual loads below 3 watts are handled as a gross load under control of the instructor. So that variations in loads under different voltages can be accounted for, a straight line curve fit is computed to calculate the load as a function of the bus voltage.

(3) Electrical Load summation

$$PLMB1 = \text{Loads} \cdot K_{\text{voltage curve}}$$

where E_{TR} = Voltage of Transformer Rectifier unit

I_{TR} = Current out of Transformer Rectifier unit

Q_{TR} = Heat generated in Transformer Rectifier unit

Eff = Efficiency of unit

P_{LMB1} = Load in main bus 1

K = Coefficient of slope of voltage/power curve

The power generation equations calculate the voltages of the storage batteries and the fuel cells and the heat and water by-products.

(4) Battery Voltage

$$B_{SOC} = f(B_{SOC}, B_{TEMP}, \text{Eff}, I_B)$$

$$E_B = f(B_{SOC}, B_{TEMP}, I_B)$$

(5) Battery Heat generated

$$Q_B = f(I_B, \text{Eff})$$

(6) Charger Heat generated

$$Q_C = f(I_C, \text{Eff})$$

where: B_{SOC} = Battery state of charge

B_{TEMP} = Battery temperature

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Eff = Efficiency of battery current conversion

I_B = Current out of battery

E_B = Battery terminal voltage

Q_B = Battery heat generated by current flow

Q_C = Charger heat generated by current flow

The generation of power by the fuel cells requires that the inlet conditions of reactants be tightly controlled. Simulation of the oxygen and hydrogen supply also requires modeling the gaseous nitrogen pressurant supply. In Figure 3.3.1.1.2 a general flowchart of the software interfaces is shown. The valve and control logic equations model the real world system response to crew station switch and circuit breaker position with electrical power available. Display parameters are generated for valve repeater flag states.

Valve position is used by the Nitrogen System equations to calculate the pressure exerted on the cryogenic liquids. The heat absorbed by the two cold fluids will be used to calculate the volume of liquid and volume of gas in the cryogenic tanks. A heat balance model will be developed for the exchange of heat/temperature with the ECS subsystem. Gaseous oxygen usage will be simulated for the atmospheric model simulation of ECS. Refer to Section 3.3.7.3 for the method of simulation of conductive and radiative heating.

The usage of oxygen and hydrogen will be computed by empirical formula:

$$O_2 = K_1 \times I \text{ lbs/hr.}$$

$$H_2 = K_2 \times I \text{ lbs/hrs.}$$

where O_2 = oxygen mass flow rate

H_2 = hydrogen mass flow rate

K_1, K_2 = empirical constants

I = electrical current

The electrical potential will be reduced by a lower nitrogen pressure differential than nominal for the cell. In addition the electrical potential will be increased with increasing operating temperature. Both of the functions will be curve fitted approximations to performance data.

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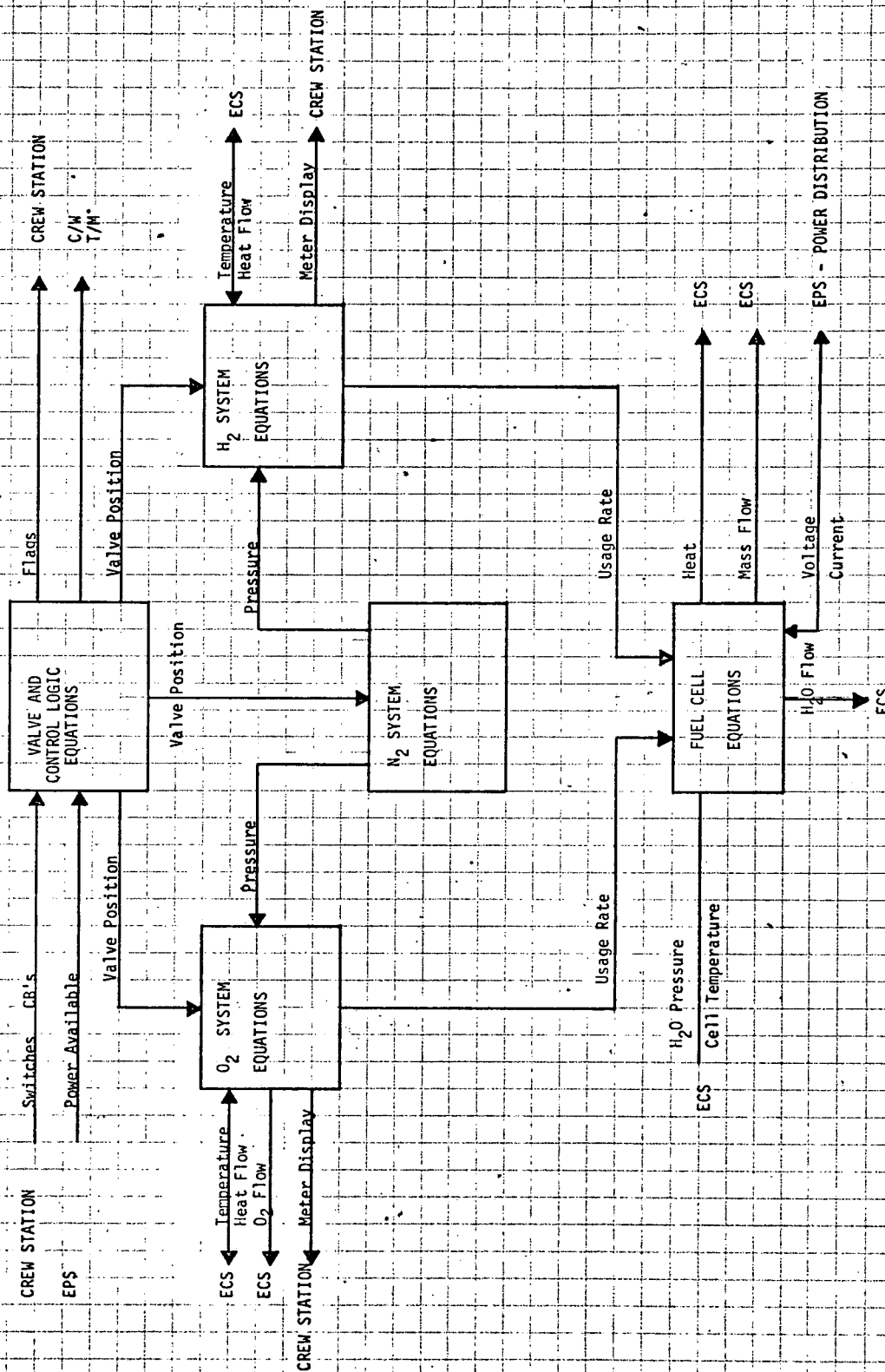


FIGURE 3.3.1.1.2 FUEL CELL SYSTEM

The power distribution equations will calculate the voltage of each major bus and the currents to or from the bus. The mathematical approach is the nodal analysis method which was used on the Skylab Simulator. This method gives an explicit solution to the bus voltage calculations. Using the bus voltages it is then possible to calculate all interbus currents from the voltage differential and the conductance.

The general form of the nodal equation solution is in the form:

$$E = \frac{\sum V \cdot G}{\sum G}$$

where: E = Node voltage

V = driving source voltage

G = Conductance in nodal network

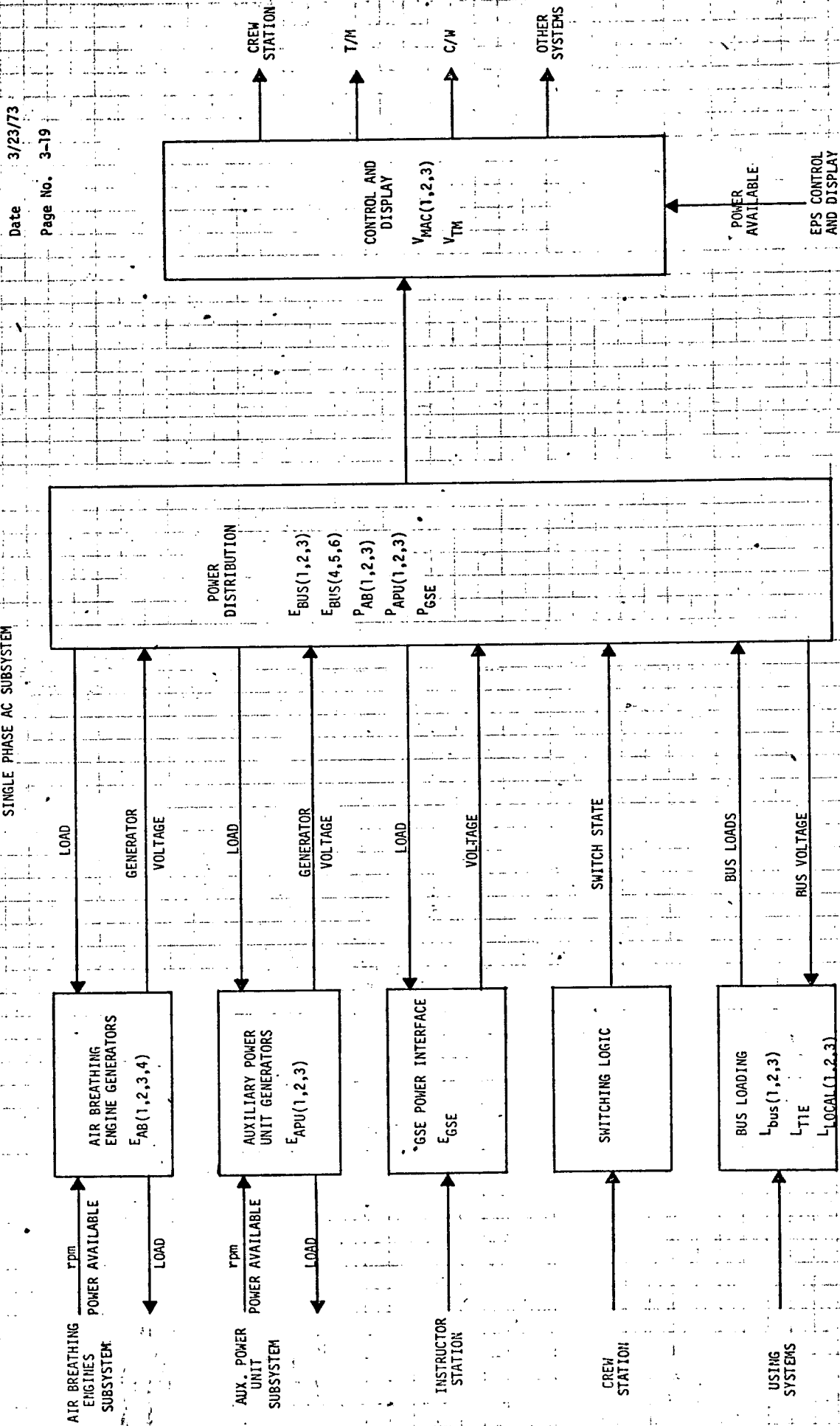
Figure 3.3.1.1.3 shows the proposed groups of equations required for the simulation of the single phase AC subsystem network.

The power sources for this network are the Air Breathing Engine generators, the APU generators, and the GSE power. For the purposes of simulation, the loads are assumed to have an overall power factor of 1.0. It is also assumed that the generators cannot be brought into sync for load sharing between units.

The Air Breathing Engine generator equations give the output frequency as a function of the generator rpm. The voltage output of the generator will

FIGURE 3.3.1.1.3

SINGLE PHASE AC SUBSYSTEM



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be a function of both rpm and the power load. Since the frequency is not displayed but is probably supplied to Caution and Warning as an out of tolerance condition, only a boolean expressing the frequency condition will be generated.

$$E_{AB} = f(\text{rpm}, \text{load})$$

$$W_{AB} = f(\text{rpm})$$

The generators driven by the APU are basically the same as the Air Breathing Engine except that both frequency and voltage may be controlled by the generator control unit through speed and field control.

$$E_{APU} = f(\text{rpm}, \text{load})$$

$$W_{APU} = f(\text{rpm})$$

The GSE power interface will be by instructor control for simulating mating cable connections and for power source supply voltage and power.

The switching logic equations calculate the state of the power control relays as a function of crew switch, circuit breaker position and up-link commands. The switch state is provided to the power distribution program to establish path conductances.

The bus loading equations provide summations of all electrical loads on the single phase AC buses. Small loads below 3 watts are to be handled as a composite load variable by instructor control.

The power distribution equations will calculate the voltage of each major bus and the total load on each source generator. Under the assumptions that the power factor for the overall loads is 1.0 and the generator cannot be in sync, the solution reduces to the equation:

$$E = \frac{V G}{G_1 + G}$$

$$P = VEG_1$$

where: E = Bus voltage
V = Source voltage
G = line conductance, source to bus
 G_1 = load conductance
P = Power consumed

The Control and Display equations use the booleans generated by the DC control and display equations to condition parameters for crew display, Caution and Warning, and telemetry programs.

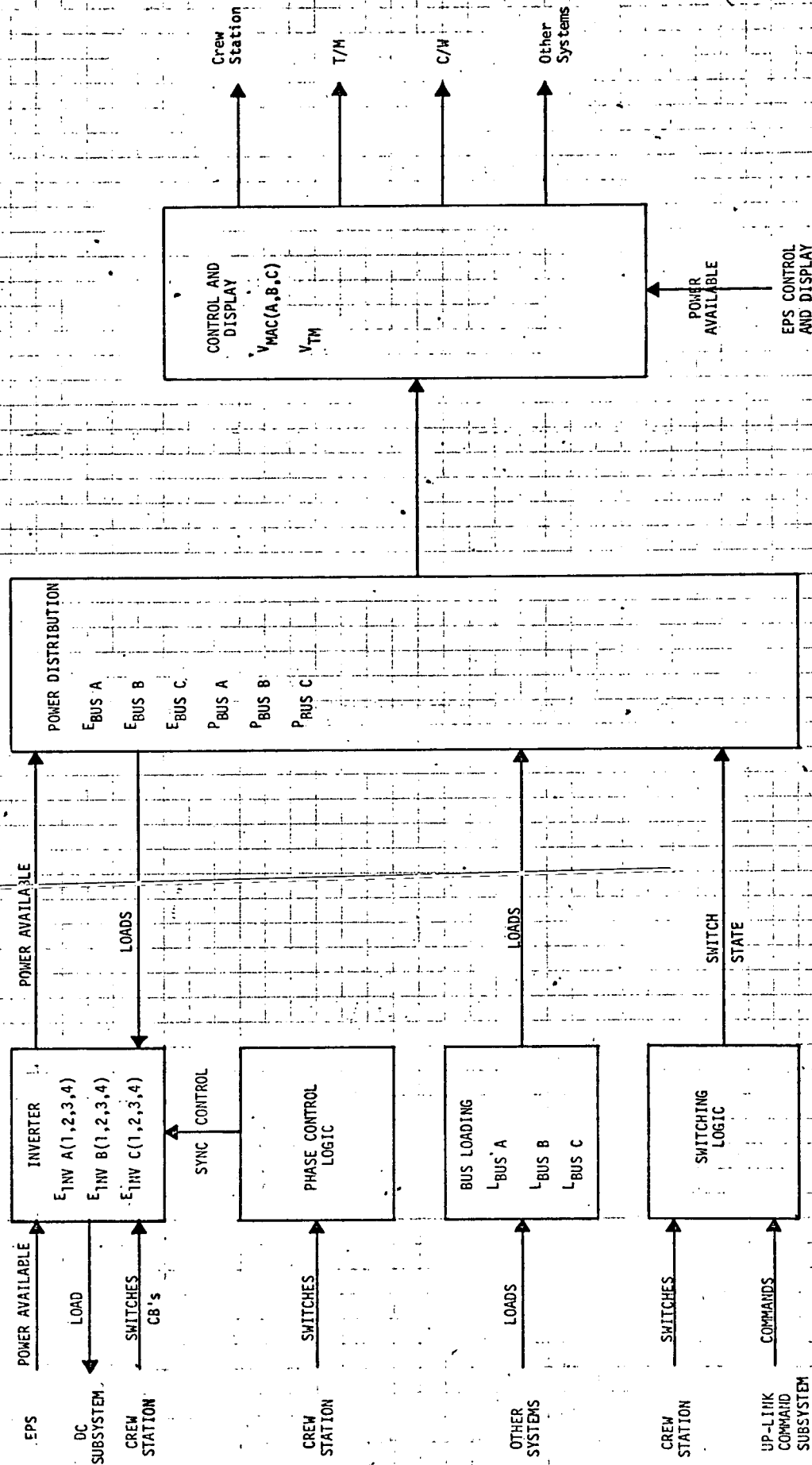
Figure 3.3.1.1.4 shows the general equation groups required for simulation of the three phase AC subsystem. The subsystem simulation is very similar to the single phase subsystem with one significant difference. Loss of a single phase will not cause shutdown of the equipment in the three phase subsystem as it would do in the single phase subsystem. Where one phase is out in the three phase subsystem, the two supporting buses will reflect increased loading.

For simulation purposes the loads on each leg are assumed to have an overall power factor of 1.0. For the three phased subsystem, it is assumed that the units sync immediately from the master sync line of the selected unit.

The sources of three phase power are the four static inverters, each capable of supplying the master sync and three phase power. Each inverter may be connected to a maximum of two bus sets. It is assumed that an inverter will fail safe on loss of the input sync signal. A boolean will be generated for a frequency out-of-tolerance condition if required by the Caution and Warning or Telemetry programs. The output voltage on each leg of the inverter is a function of the leg load.

$$E_{INV(A,B,C)} = f(\text{load})$$

FIGURE 3.3.1.1.4
THREE PHASE AC SUBSYSTEM



The bus loading equations supply a summation of the loads on each bus leg. The switching logic equations calculate the switch and relay state based on switch, circuit breaker, and up-link command logic.

The power distribution equations will calculate the voltage of each major bus and the load on each inverter unit. Under the assumptions stated, the power distribution equations reduce to:

$$E_{\text{BUSA}} = \frac{V_1 G_1 + V_2 G_2}{G_1 + G_2 + G} \quad (\text{Typical})$$

$$P_{1\text{BUSA}} = (V_1 - E_{\text{BUSA}}) G_1 \quad (\text{Typical})$$

where: E_{BUSA} = Bus voltage (Phase A shown)

V_1 = Inverter #1 Voltage (Phase A)

V_2 = Inverter #2 Voltage (Phase A)

G_1 = Line conductance, inverter 1 to bus

G_2 = Line conductance, inverter 2 to bus

G = Load conductance, Phase A.

$P_{1\text{BUSA}}$ = Power to Bus A from inverter 1, Phase A

The control and display equations to be used by the three phase subsystem are combined with the single phase subsystem outputs. The reason is only one crew station display is provided for the AC voltages.

The computer will provide control over circuit breakers during periods of simulated high currents. Upon calculation of an overcurrent of 150% of the circuit breaker rating, the circuit breaker will be set open. The circuit breaker control routine of the control and display equations will also provide simulated defective circuit breakers which cannot be reset and hold. Malfunctions will also be provided for intermittent shorts causing circuit breaker opening.

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The equations of the EPS simulation will be repeated for each unit either by programmed loops or repetitive equations, whichever design uses the least amount of time and core. The required malfunctions for the EPS simulation will be designed into the equations for minimum computer impact.

3.3.1.2 Auxiliary Power Unit Subsystem

The Auxiliary Power Unit simulation will be divided into six basic areas of equations. See Figure 3.3.1.2. These mathematical representations of the real world system could be written in engineering equations which may be derived. Engineering equations are normally required for simulation where systems are highly instrumented. At present, however, the crew has minimum controls and displays relating to the APU operation. All control inputs apparently actuate automatic sequencer logic for both start up and shutdown of the turbines. Since the crew also has minimum displays, realistic functional equations will be written to generate the required display parameters with a minimum impact on computer time and core loading.

The shaft loading equations will calculate the mechanical loads on the turbine engine. Inputs to the program will be provided by the Hydraulic System and the Electrical Power System. The loading equations are to include the effect of friction and windage and the lube pump load.

$$L_s = (L_H + L_E + L_{LP} + L_K) / K_{eff}$$

where L_s = Shaft load on turbine

L_H = Hydraulic loads

L_E = Electrical loads

L_{LP} = Lube pump loads

L_K = Friction and windage loads

K_{eff} = Mechanical efficiency

The control logic equations are to provide simulation of valve state as the result of crew switch and circuit breaker inputs. Timing delays are to be incorporated only where the response would be detected by the crew.

The Helium pressurization simulations will calculate the amount of helium (pressure, temperature, mass) in the pressurization bottles and the pressure in the hydrazine tank. The gaseous volume and gas pressure will be calculated using the fuel quantity remaining in the hydrazine tank.

$$V_H = V_T - V_F$$

$$M_H = P_H V_H / R T_H$$

where V_H = Volume of helium

V_T = Volume of fuel tank - constant

V_F = Volume of fuel

P_H = Pressure of helium

M_H = Mass of helium

R = Universal gas constant

T_H = Temperature of helium

and

$$M_{HP} = M_O - M_H$$

$$P_{HP} = M_{HP} R T_{HP} / V_{HP}$$

where M_{HP} = Mass of helium in high pressure tank

M_O = Mass of helium - originally in tank - constant

P_{HP} = Pressure of helium - high pressure tank

T_{HP} = Temperature of helium - high pressure tank

V_{HP} = Volume of high pressure helium tank - constant

The fuel equations will provide not only the fuel quantity integration but the supply pressure to the gas generator. These equations are to take into account valving between the fuel tanks and the gas generator.

$$P_F = P_H$$

$$Q_F = Q_F - Q_C$$

where P_F = Pressure of fuel on gas generator

Q_F = Fuel quantity remaining

Q_C = Fuel quantity consumed

The gas generator equations will include logic and functional transforms simulating the generation of gas. The gas generator equations will include conditional parameters for valve state to the turbine engine control valves. Electrical power usage will be calculated for EPS bus loading.

$$G_G = f(t_H, P_F)$$

where G_G = Gas generation

t_H = Heater warm-up time

The turbine engine equations will calculate the functional engine speed, exhaust temperature, and fuel consumption rate based on the shaft loads. Power available booleans are also to be provided to the subsystems of Electrical Power and Hydraulic Power. Start up and shutdown sequences are to be functionally simulated.

$$R_{pm} = f(G_G, P_F, L_s, t_s)$$

where R_{pm} = Turbine R_{pm}

t_s = time from start-up or time from start of shutdown

From these groups of equations, parameters simulating the actual system state will be conditioned using sensor and display logic booleans from the Electrical Power System for crew station display, for input to the Caution and Warning System, or for input to the Telemetry Multiplexer Program. The equations will be repeated for each auxiliary power unit, either by programmed loops or

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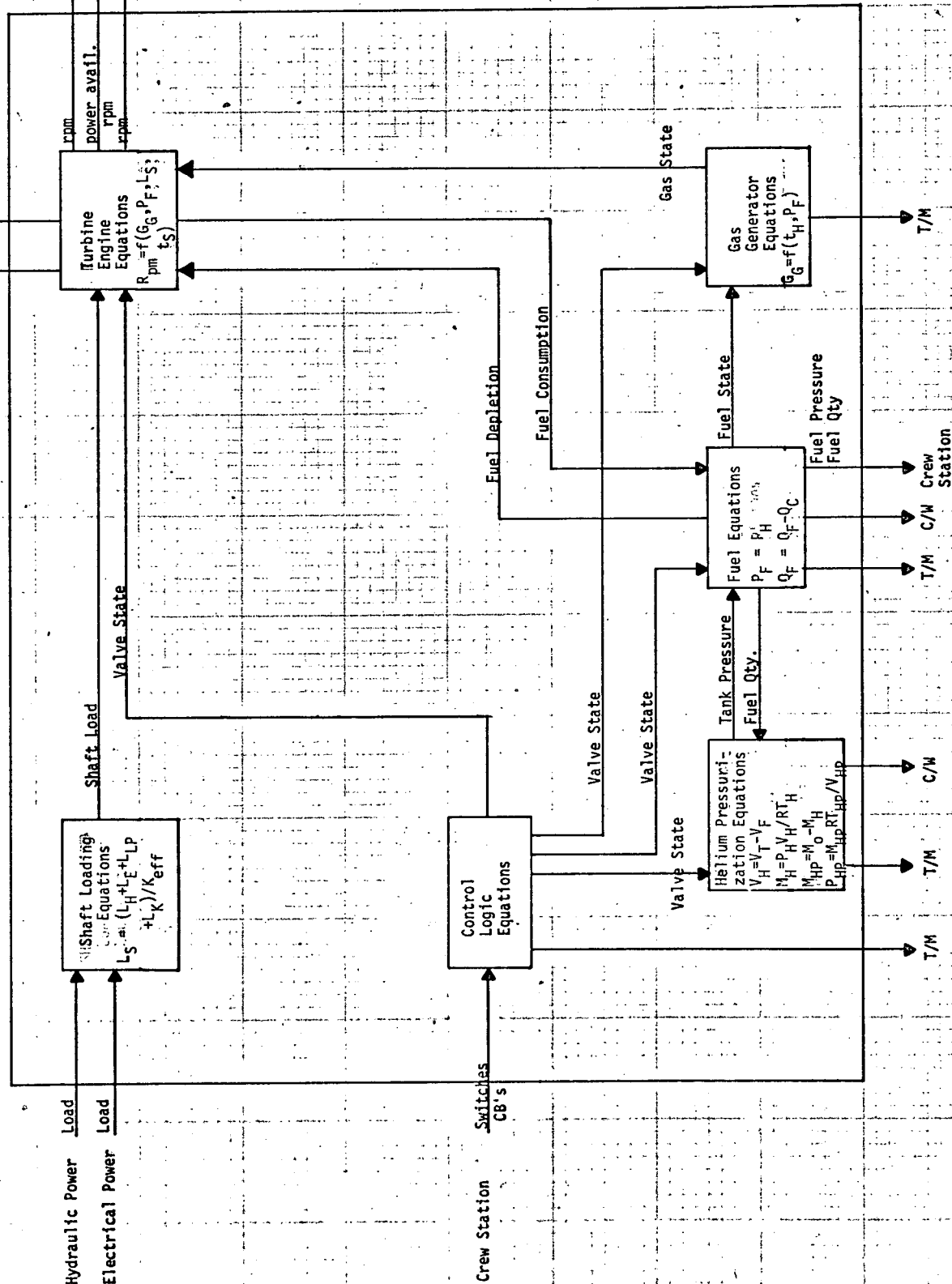
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by repetitive equations, whichever requires the least amount of computer time and core. Required malfunctions for the APU are to be designed into the simulation for minimum computer impact.

Figure 3.3.1.2 - Auxiliary Power Unit Subsystem



T/M - Telemetry System

C/W - Caution/Warning System

3.3.1.3 Hydraulic Power Subsystem

The Hydraulic Power Subsystem will be divided into four blocks of generally related equations for simulation purposes. Figure 3.3.1.3 shows the interfaces of these equation groups. The mathematical equations used as representative of the real world system could be derived engineering functions, however, the crew station controls and displays are minimal. At present, the crew displays are limited to hydraulic fluid temperature and quantity. Caution and Warning displays relate to high and low fluid temperature, low fluid quantity, and low pressure. Realistic functional equations will be written to generate the required display parameters without an excessive computer time requirement.

Two of the hydraulic power using subsystems, Aerodynamic Control Surfaces and Thrust Vector Control, require large quantities of fluid. Interface requirements, as the result of the servo loop hydraulic system, dictate that the Hydraulic System simulation of load versus power run at the same iteration rate as these subsystems (or twenty to ten iterations per second). This requirement, in addition to the minimum displays, justifies the functional approach to simulation of this system.

The loading equations will calculate the summation of the fluid flow from the four main supply lines. The program will also calculate flow from the main supply lines to the two accumulators. These fluid flow summations form load request parameters for the pump-reservoir equations and the accumulator equations. The load request parameters are to be generated by the using systems for elevons, rudder-speed brake, main engine TVC, engine controls, OMS TVC, SRM TVC, gear uplock, gear deployment/retraction, wheel braking, steering, RCS door operation, and payload bay doors.

$$H_L = \sum H_{L1} + H_{L2} \dots$$

Where H_L = hydraulic load on supply main-gpm

H_{L1} , H_{L2} = individual load requests.

The accumulator equations will simulate the stored power by calculating a load response factor for all units that use accumulator hydraulic pressure. This load response factor is a function of the mass, temperature, and volume occupied by the entrapped gas. The volume occupied by the gas will be calculated by a summation of hydraulic fluid usage and resupply for the accumulator. Load requests will be generated by the equations for use in the loading equations as hydraulic fluid is used from the accumulator.

The limit of the pressure within the accumulator is set by the hydraulic supply.

$$V_G = M_G R T_G / P_G$$

Where P_G = Pressure on accumulator gas or hydraulic pressure if it exceeds internal accumulator pressure.

M_G = Mass of gas in accumulator

T_G = Temperature of gas in accumulator

V_G = Volume of gas in accumulator

R = Universal Gas Constant

The volume occupied by the gas is the volume of the accumulator tank less the volume of hydraulic fluid.

$$V_G = V_T - V_H$$

Where V_T = Accumulator tank volume

V_H = Volume of hydraulic fluid in the accumulator.

During the expansion cycle the pressure in the accumulator is expressed by

$$P_G = M_G R T_G / V_G$$

The pump-reservoir equations are to simulate the four sources of power to each manifold supply pipe. The pumps are the two APU gear pumps, the ABPS gear pump, and the AC driven circulation gear pump. Simulation logic will be incorporated to prevent back flow into these pumps where check valves exist. Relief and by-pass valves will be logically represented for equation usage. A summation of total pump capability will be made to furnish a load response factor for using subsystems based on load request. Reservoir quantity will be calculated from a summation of pump usage-return fluids to the reservoir.

During simulation in real time, the load response factor will allow using subsystems to react in a realistic maneuver when an hydraulic flow (or load) request is made which exceeds the capability of the pump (or pumps) on-line to supply the volume of fluid requested at the design pressure.

The time response of systems is computed by a load response factor or a factor expressing the percentage of the requested load that was supplied by overloaded pumps.

$$H_F = f(H_L, H_P)$$

or

$$H_F = \frac{H_L}{H_P}$$

Where the hydraulic load H_L is less than the total pump capability on the manifold, the response factor H_F will be set to 1.0. If the load request exceeds the pumping capability, the hydraulic load response factor is calculated by dividing the total requested hydraulic load by the pumping capability. Each using subsystem may then calculate the percentage of motion achieved at the low volume flow and then recalculate a new hydraulic load request.

A heat load is to be calculated for heat balance equation usage to determine the temperature of the hydraulic fluid. The calculation of temperature of the hydraulic fluid will take into account coolant valve positions as the result of crew switch, circuit breaker, and electrical power conditions. Interface parameters of heat load on the water boiler heat exchanger will be calculated for use by the ECS Subsystem simulation. The ECS Subsystem will calculate a return fluid temperature for use by the heat balance equations.

The heat added to the hydraulic fluid is calculated by the amount of work or electric energy added.

$$Q = f(W) + H_E$$

Where Q = heat added

W = work done on hydraulic fluid

H_E = electrical energy added

From these groups of equations, parameters simulating the actual system state will be conditioned using sensor and display logic booleans from the Electrical Power System for crew station display, for input to the Caution and Warning Subsystem, or for input to the Telemetry Subsystem Multiplexer Program. The equations will be repeated for each hydraulic pump and manifold supply pipe, either by programmed loops or by repetitive equations, whichever requires the least amount of computer time and core. Required malfunctions for the Hydraulic System are to be designed into the simulation for minimum computer impact.

Heat balance, sensor, signal conditioning, and temperature calculations will be accomplished on an iteration rate of five or two per second by internal program logic.

3.3.2 Propulsion System

3.3.2.1 Main Engine Subsystem

The presentation of the conceptual design of the Shuttle Main Engine simulation is divided into sections as shown in Figure 3.3.2.1. The problems that are to be encountered in the design of the program are first discussed. The Main Engine simulation using a functional model is then discussed. The next discussion concerns the simulation technique that could be used for the controller model, first using the flight software program and secondly using a functional approach.

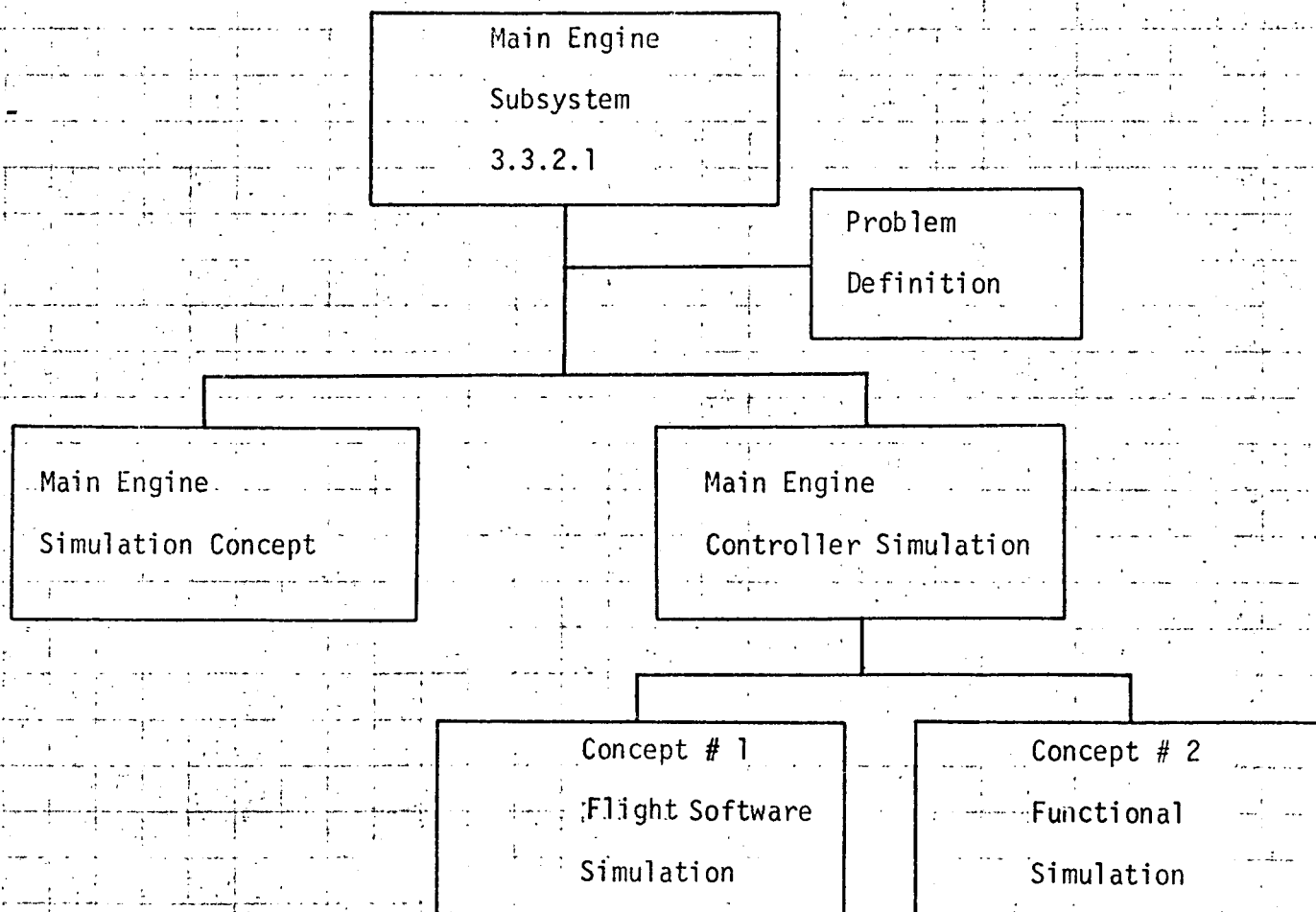


Figure 3.3.2.1

Problem Definition

The real time simulation of the main engine system during nominal boost phase must be accomplished with a fidelity that results in the time and conditions of orbital entry being almost exactly the same as the expected flight trajectory data. One of the nominal flight profile requirements which impacts the simulation method is the ± 0.5 second accuracy in time of burn from liftoff to orbital insertion. To achieve the time requirement dictates that both engine thrust and vehicle mass be accurately modeled. The two main contributing systems to thrust and mass change are the main engine and the solid rocket motors.

The simulation of the main engine controller and it's interfaces with the main engine and the GNC computer may be approached by using either a functional controller model or by using dedicated computers capable of accepting the flight computer software. The greatest problem to be overcome by either approach is the data computation rate differences and time response of the system caused by the interfacing computer units.

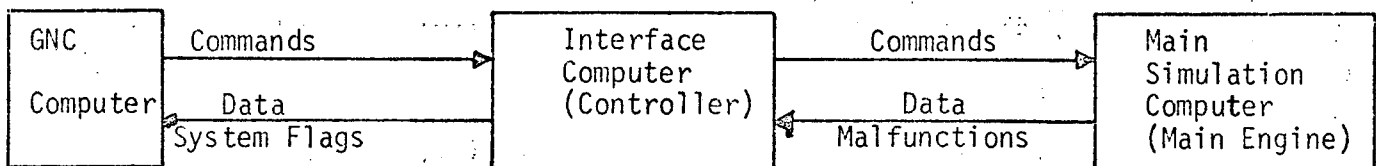


Figure 3.3.2.1-1

The interface/time response problem is one of having computer programs with different basic interaction rate cycles. The GNC computer has a basic rate of 25 cps; the "controller" computer has 200 cps, 100 cps, 50 cps, 25 cps, and lower; and the main engine computation has 20 cps and lower. The low rate data requirements below 20 cps present no particular problem to the main computer, however the 25 cps to 200 cps present major interface problems. Simulation of engine data in a functional model at rates of 50 and 100 samples per second is prohibitive on the main

computer time.

In the controller computer flight software program, command response comparison tests are conducted against internally calculated values for engine chamber pressure data and engine control valve actuation position at high data sample rates. If in the comparison the parameter is out of tolerance by comparison to the expected calculated value, the software program will initiate a program to test three samples of the parameter at a rate of 200 samples/second. If the three samples are out-of-tolerance, either engine limit shutdown or other corrective action will be taken by the controller.

The conceptual design for simulation of the SSME is based on interface requirements with, and determined by, the main engine controller computers. The main engine controllers are required to perform the following functions in regard to interfacing with the main engines:

- A. Provide closed loop control at a rate of 50 times per second (every 20 milliseconds) for start, shutdown, and mainstage control.
- B. Provide output electronics to command the engines' proportional actuators, solenoid coils, and spark igniters.
- C. Receive and process main engine performance and operational status data.

The controllers interface with and provide signal conditioning, multiplexing, and analog to digital conversion for 77 sensor signals and 93 analog built-in test signals.

- D. Provide built-in test hardware and software programs to validate the avionics and engine system by conducting automatic self tests every 20 milliseconds, performing engine checkout on vehicle command, and performing engine limit monitoring.
- E. Monitor engine readiness to start and provide an engine ready signal

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to the vehicle.

F. Control SSME system purges upon vehicle command

A basic design requirement for the SSME simulation is to provide data from within the simulated system to properly interface with the main engine controller. For the SMS the main engine controller may be simulated by the usage of flight hardware, or a non-flight rated equivalent commercial computer, or a functional simulation performed by software programmed within the SMS host computer. The simulation interface is determined by the engine information which is processed through the input and output electronics (see Figure 3.3.2.1-2) of the main engine controller. Performance characteristics of engine interface requirements of the controller are discussed in the following paragraphs. (Refer to Appendix for Tables Reference.)

Thrust Control

The controller provides continuously variable engine thrust control between MPL and EPL as commanded by the vehicle. Thrust commands received from the vehicle which exceed EPL cause thrust to be controlled at 109 percent NPL. Thrust commands received from the vehicle which are less than MPL cause thrust to be controlled at MPL. The thrust control loop consists of controller logic and driver circuits to receive a thrust level command from the vehicle and position the fuel preburner oxidizer valve and the oxidizer preburner oxidizer valve to achieve the commanded thrust level as determined from the main combustion chamber combustion pressure measurements. The controller provides a computer value from the fuel flowrate and the oxidizer flowrate to be used as an alternate thrust measurement in the event of the loss of the main combustion chamber combustion pressure measurement. The thrust control loop contains provisions for both fuel preburner and oxidizer preburner temperature control within the limits specified in Table I, Temperature Limit Control Range and Nominal Control Point Values. The control is enabled subsequent to receiving a Limit Control Enable command from the vehicle and is disabled

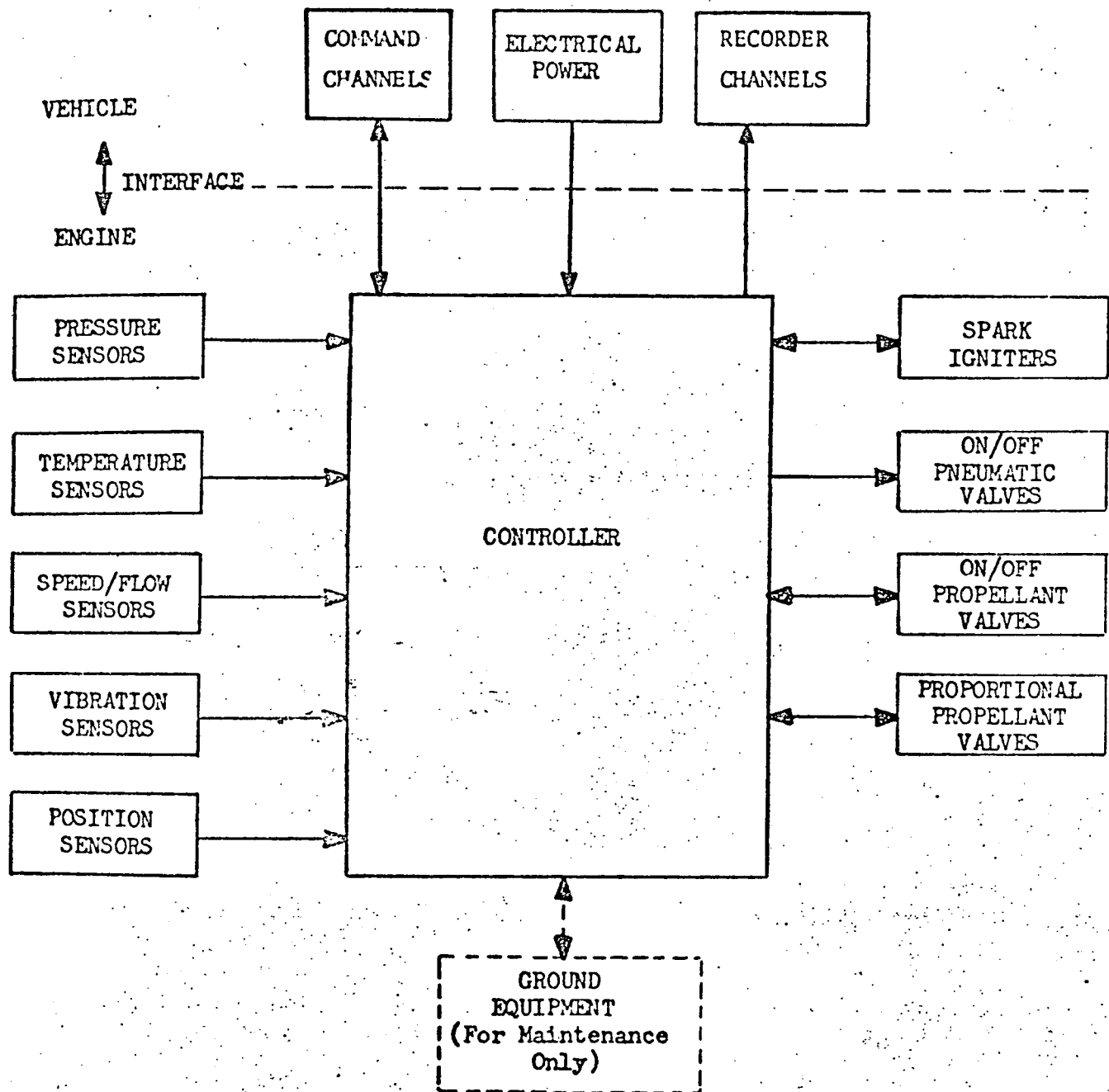


FIGURE 3.3.2.1-2
CONTROLLER INTERFACES

subsequent to receiving a Limit Control Inhibit command from the vehicle.

Thrust Control Precision

The controller controls engine thrust to within plus or minus 6,000 pound force (3 sigma precision) of the commanded value during steady-state operation and during thrust throttling where commanded thrust changes at rates equal to or less than 7,000 pounds per second.

Thrust Level Change

The controller is capable of accepting step commands in thrust level from the vehicle and provides rate limiting to limit engine thrust rate of change to greater than 120,000 pounds force per second and equal to or less than 7,000 pounds force per 10 milliseconds.

Scheduled Valves

Schedule requirements for valves, whose positions are to be scheduled as a function of time, thrust, or thrust reference are provided by the controller.

Mixture Ratio Control

The controller is capable of providing continuously variable oxygen/hydrogen mixture ratio control as commanded by the vehicle, for thrust levels between MPL and EPL. Mixture ratio commands received from the vehicle which exceed 6.5 cause mixture ratio to be controlled at 6.5. Mixture ratio commands received from the vehicle which are less than 5.5 cause mixture ratio to be controlled at 5.5. The mixture ratio control loop consists of controller logic and driver circuits to receive commands from the vehicle and vary the mixture ratio by positioning of the fuel preburner oxidizer valve and the oxidizer preburner oxidizer valve, if necessary, using the fuel flowrate and oxidizer flowrate for the primary method of mixture ratio determination.

Mixture Ratio Precision

The controller controls mixture ratio to within plus or minus 1 percent

(3 sigma precision) of the commanded value during the steady-state operation.

Actuator Position Control

The controller provides analog closed-loop position control of modulating propellant valve actuators. The controller models and monitors servovalve positions for failure detection purposes.

Sensor Provisions

The controller receives triple redundant inputs from sensors used in engine performance control and performing sensor failure detection. The controller also receives dual redundant inputs from sensors used in limit detection and engine readiness checks and performs failure detection to ensure sensor fail-operational failsafe performance.

Spark Igniter/Actuator/Valve Provisions

The controller provides dual redundant outputs to spark igniters, actuators and the on/off valves with dual coils and performs failure detection of spark igniter, actuator, or valve failures to ensure system fail-operational failsafe performance. Failures are detected by monitoring igniter spark rate and voltage, actuator position and servovalve position.

Limit Shutdown

The controller performs a continuous self-test of the engine control and monitor system. The controller monitors critical engine parameters during engine operation in accordance with Table II, Engine Limit Control Shutdown Parameters. If an engine limit is detected, the controller shutdowns the engine only if the Limit Control Enable command of Table IV, Vehicle to Engine Commands, has been invoked by the vehicle.

Checkout and Monitoring

The controller contains on-board checkout and Built-In Test Equipment (BITE) for ground and flight operations. This includes as a minimum, the capability of all redundancy verification and status monitoring for engine system verification. The

controller is capable of identifying the failures listed in Table III, Failure Identification.

Component Checkout

The controller is capable of performing checkout of individual control components or groups of components upon command from the vehicle. The items which shall be individually checked out include:

- A. Each propellant valve/actuator
- B. Each pneumatic solenoid valve
- C. All sensors, as a group
- D. All spark igniters, as a group

Pressure Sensor Checkout

The controller contains provisions to individually connect two resistive loads, contained in each pressure sensor, in parallel with one leg of the sensor bridges during checkout. This will produce simulated sensor outputs of 20 and 80 percent of full scale (nominal), respectively, which are monitored by the controller for verification of pressure sensor electrical function and pressure sensing element working condition.

Temperature Sensor Checkout

The controller performs checkout of the temperature sensors by inserting a resistive load, contained in the controller, into each temperature sensing circuit to produce a simulated sensor output of 50 percent of full scale (nominal).

Flow/Speed Sensor Checkout

Each flow and speed sensor contains dual redundant output windings. The controller performs checkout of these sensors by exciting one of the sensor windings with test signals and monitoring the output produced by inductive coupling in the other sensor output winding. The test signals consist of AC(sine wave) voltages at a frequency of 10 and 90 percent of the full scale pulse rate output (nominal)

of each respective sensor. The nominal voltage level of the test signals are equal to the voltage level nominally produced by the sensors at the respective test frequency.

Propellant Valve/Actuator Checkout

The controller contains provisions to checkout each propellant valve and associated actuator including all redundancy. Hydraulic fluid, at system operating pressure, is supplied to the actuators from an external source. Checkout includes the ability to measure and evaluate items such as actuator position error, valve spool position error, torque motor driving signal error, math model comparator output, and actuator dynamic response to a step input.

Pneumatic Solenoid Valve Checkout

The controller checks out all solenoid valve coils individually. This checkout is performed in both valve states, open and closed, by monitoring selected engine parameters that would be directly affected by the valve operation.

The controller monitors the steady-state valve current for pull-in, hold-in and unenergized conditions.

Spark Igniter Checkout

The controller provides input power and control signals to the spark igniters as a group and verifies each spark igniter monitor signal. The monitor signal is verified in amplitude and frequency.

Monitored Redlines

The controller is capable of monitoring all critical engine parameters for a prestart redline condition. Verification of satisfactory prestart conditions result in the issuance of an Engine Ready status signal to the vehicle.

In-Flight Monitoring

The controller contains provisions for a continuous monitor of the engine system during engine operation. The monitoring logic includes controller internal

operation, propellant valve actuator positions, servovalves, sensors, igniters, and the parameters listed in Table II, Engine Limit Control Shutdown Parameters. The design of the controller also includes a limit control system which is capable of automatically adjusting the power level or initiating engine shutdown to preclude engine operation outside of defined safe operating limits. The limit control system is enabled subsequent to a Limit Control Enable command from the vehicle and is disabled subsequent to a Limit Control Inhibit command from the vehicle.

Engine Commands and Data

Commands and Memory Data Words

The controller is capable of accepting and responding to the vehicle-to-engine commands specified in Table IV, Vehicle to Engine Commands.

Command words and memory data words from the vehicle will consist of a total of thirty-one bits; fifteen bits for encoding and sixteen bits for command and/or memory data. The BCH encoding will enable detecting and rejecting error patterns according to the capability of a polynomial (TBD). Commands from the vehicle will consist of two basic types of commands. These are defined as absolute commands (i.e., thrust and mixture ratio). Absolute commands will agree exactly in content for all operable command channels. Voting with 3 good channels, 2 of 3 agreement will constitute a good vote. After 1st channel failure, 2 out of 2 agreement will constitute a good vote. Absolute commands that do not constitute a good vote shall be disregarded. The variable command which is executed, assuming that all three channels are good, will be the average of all three variable commands after it has been determined that all three are within TBD percentage difference of each other. After the first channel failure, an average of two variables will be made to a TBD percentage difference. Command values which are outside this limit shall be disregarded. The interval between successive command words from the vehicle

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to the engine will be a minimum of 2 milliseconds. The interval between successive memory data words from the vehicle to the engine during memory loading will be a minimum of 2 milliseconds. The number of command words from the vehicle to the engine will not exceed three commands for a 20-millisecond period. The number of memory data words transmitted from the vehicle to the engine during memory loading for any 20 millisecond time period is limited only by the required interval between memory data words.

Command words and memory data words from the vehicle to the engine will be verified by:

- a) Correct number of bits per word
- b) BCH error detection of each word
- c) Direct vote of all operable inputs

The number of bits in each command and/or memory data word including the 15 BCH check bits will equal 31 bits. Command and/or memory data words from the vehicle which do not pass the number of bits per word or BCH error detection checks will be disregarded and inhibited from entering the voting. These failures will result in a "message error" response (including failed command channel information) being transmitted to the vehicle via the status/recorder channels.

Commensurate with the allowable skew between command channels, the engine will initiate voting of the command and/or memory data word from all operable command channels. A command word which is voted and determined to be invalid by the engine due to disagreement or incorrect phase of engine operation, will result in the transmission of a "message reject" code to the vehicle, via the status/recorder channels, indicating that the message has been rejected. A memory data word which is voted and determined to be invalid by the engine due to disagreement will also result

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in the transmission of a "message reject" code to the vehicle.

The transmission of the "message reject" code for command words will occur during the next status/recorder channel transmission (a maximum of 42 milliseconds after command word voting decision). The transmission of the "message reject" code for memory data words will occur following the completion of the load mode.

A "message error" response, including the failed channel identification, will be transmitted for the case of only two command channel agreement.

Command words consisting of a word sync pulse with all bits equal to a logical "zero" will be received from the vehicle whenever a command is not being transmitted or memory is not being loaded. Transmissions to the vehicle during periods of inactive transmission of engine status/recorder data or memory readout data will consist of data words containing a word sync pulse with the data bits and parity bit equal to logical "zero".

Engine Status/Recorder Data to Vehicle

The parameters listed in Table V, Engine Status Transmitted to Vehicle, are supplied to the vehicle interface upon request of the vehicle. The parameters listed in Table VI, Status/Recorder Data Transmitted to Recorder, are supplied to the vehicle interface automatically every 40 plus or minus 2 milliseconds. The engine will initiate a transmission of the parameters listed except when memory is being loaded or readout. The transmission of engine status/recorder data will not be interrupted by command words from the vehicle. Each serial digital data word on the status/recorder channels will consist of 16 bits plus a parity bit per word. The number of logical "ones" in the status/recorder channel word, including the parity bit, shall sum to an odd number. The word sync pulse, data bits, and parity bit for engine data and memory readout words will be transmitted on all status/recorder channels. The engine status word listed in Table V (data word 3) is further

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defined in Table VIII. This word is divided into seven groups of information: command status, channel status, PRT status, limit control inhibit/enable status, engine operation phase, engine operation mode, and engine self-test status. Failure identification provision is provided by data words 6, 7, and 8. Data word 6 will be a failure identification coded word and will identify the particular limit exceeded or failed item. Data word 7 will be an identifying test number associated with data word 6 and will include information concerning the number of failures experienced. This information shall cover all detectable failures and not be limited to failures which cause redundancy switching. Data word 8 will be a parameter value associated with information contained in data words 6 and 7. The data word order listed may be altered by modification of the controller's software program.

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CREW STATION CRT DATA DISPLAY

(ALTERNATE PREFERRED METHOD)

Under the guidelines of using real-world software and GNC computers, there exists the requirement to supply the GNC computers with all data transmitted from the controller to the GNC computer at the real world rate.

With this requirement the iteration rate of the interfacing computer simulating the main engine controller is fixed to the GNC rate. For the functional simulation of the main engine to supply the data transferred across the interface requires extensive processing for data to be displayed at the crew station CRT and for recording purposes.

In the past data recording, unless it can be used for on-board usage, has been simulated only when required by MCC. Since this recorded data is primarily intended for post flight maintenance it is felt that this feature is not required.

By elimination of the recorder problem, the simulation of the crew station CRT display of the main engine data can be accomplished by bypassing the controller-GNC- Data Display Computer entirely and using a direct interface between the main host computer and the crew station CRT display. This interface would require a slow one or two per second update as compared to the five per second.

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By using the functional controller approach (Method II) and supplying only those parameters actually used for comparison in the controller, the interfacing program should be able to be reduced from 429,000 instructions per second to an estimated 43,000 instructions per second. This approach would still supply the crew station with the displays required at a reasonable rate.

It is to be noted however, that this method may then require all inputs to the crew station display CRT to be via the interfacing computer. This may prove to be an advantage, in that crew station display malfunctions could be entered in all systems' displays without a multitude of interfacing parameters being transferred from the host computer to the GNC and Data Display Computer and then to the crew station CRT.

MAIN ENGINE SIMULATION CONCEPT

The simulation of the Shuttle main engines during the boost phase of the mission may be approached by several overall design concepts. The main engine thrust forces and mass calculations during a nominal boost phase require a high degree of accuracy so that the burn time to reach orbital velocity compares within 0.5 second to the reference trajectory. To match the reference trajectory data, the engine simulation of thrust and mass would have the desired accuracy required to represent the engine in normal operation. In an off-nominal or abort situation, the simulation would use only the functional model. The functional model must be designed so that minimum corrective techniques are used to adjust the simulation to the reference trajectory. It may then be assumed that in off-nominal situations the engine model is fairly realistic to the real world design.

An alternate approach would be to use the functional model of the engine to match the reference trajectory. This method has been used in the Apollo real-time simulators; however, the program required modification of coefficients each time a new reference trajectory was released so that engine cut-off time could be matched. Because of the variety of trajectories and the short time of incorporation of reference trajectory required, this method would require a large man-hour expenditure for each trajectory change.

A third approach would be to use the reference trajectory parameters as a table look-up with curve fit functions used to calculate intermediate time point data. This method yields the most accurate representation of the nominal reference trajectory, but does not solve the problem of off-nominal operating conditions. The off-nominal situation could be simulated using

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a functional engine model; however, it is felt that this method is highly undesirable for minor variations to the simulation.

A generalized functional system concept for simulation is shown in Figure 3.3.2.1-3. This figure shows the major functions of the main engine functional simulation. The simulation model will accept crew station switch and circuit breaker status and internal switching logic to determine valve and display position. Electrical power available will be provided by the EPS simulation. The ECS simulation will be provided with base heating rates for thermal modeling as required. Telemetered data and inputs to the C/W model will be provided by functional simulation within the main simulation computer without using the interface controller computer. Controller status will be interfaced to provide correct simulation fidelity for those required functions. These general interfaces are shown in Figure 3.3.2.1-4. Refer also to Figure 3.3.2.1-7.

HELIUM REPRESSURIZATION

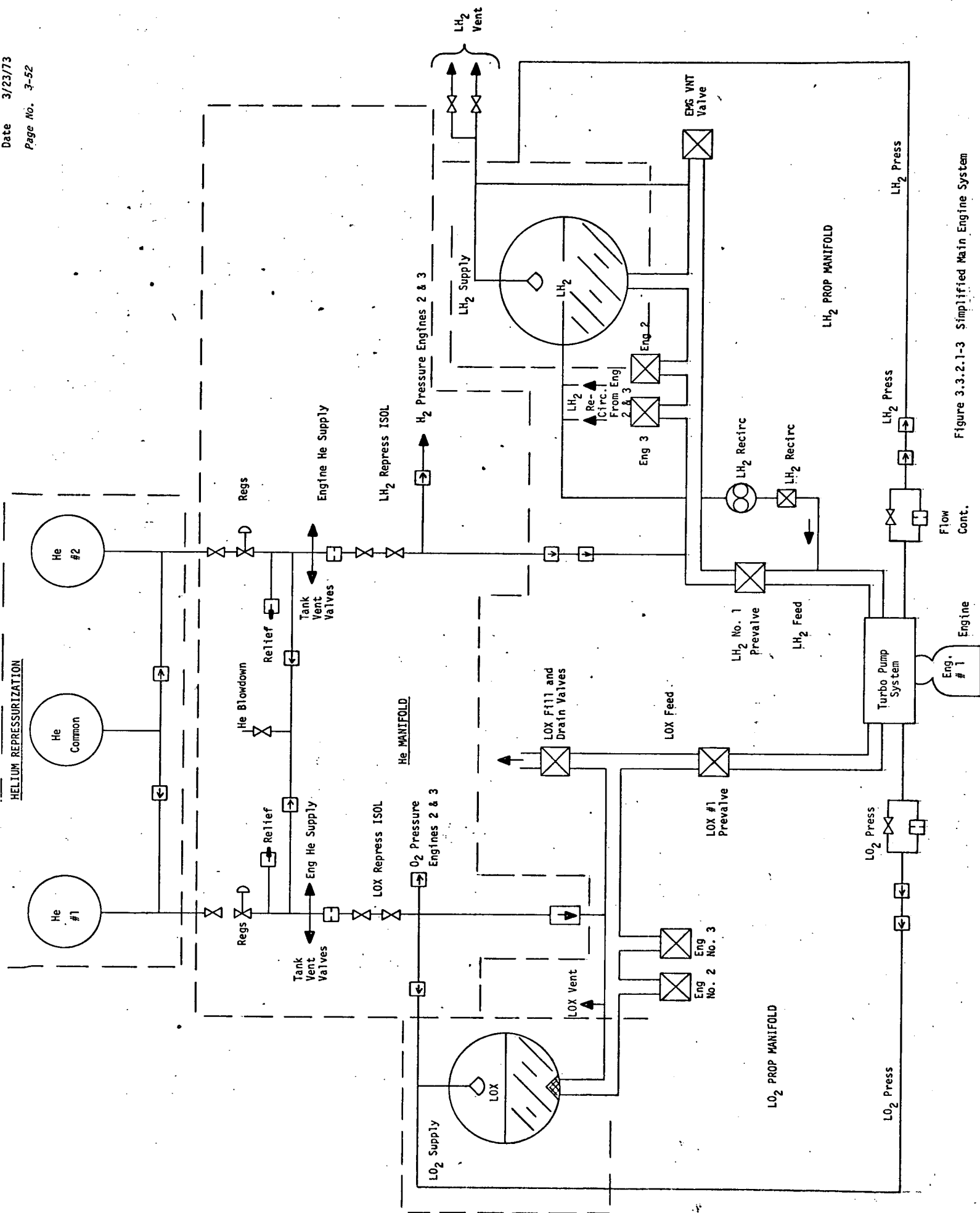


Figure 3.3.2.1-3 Simplified Main Engine System

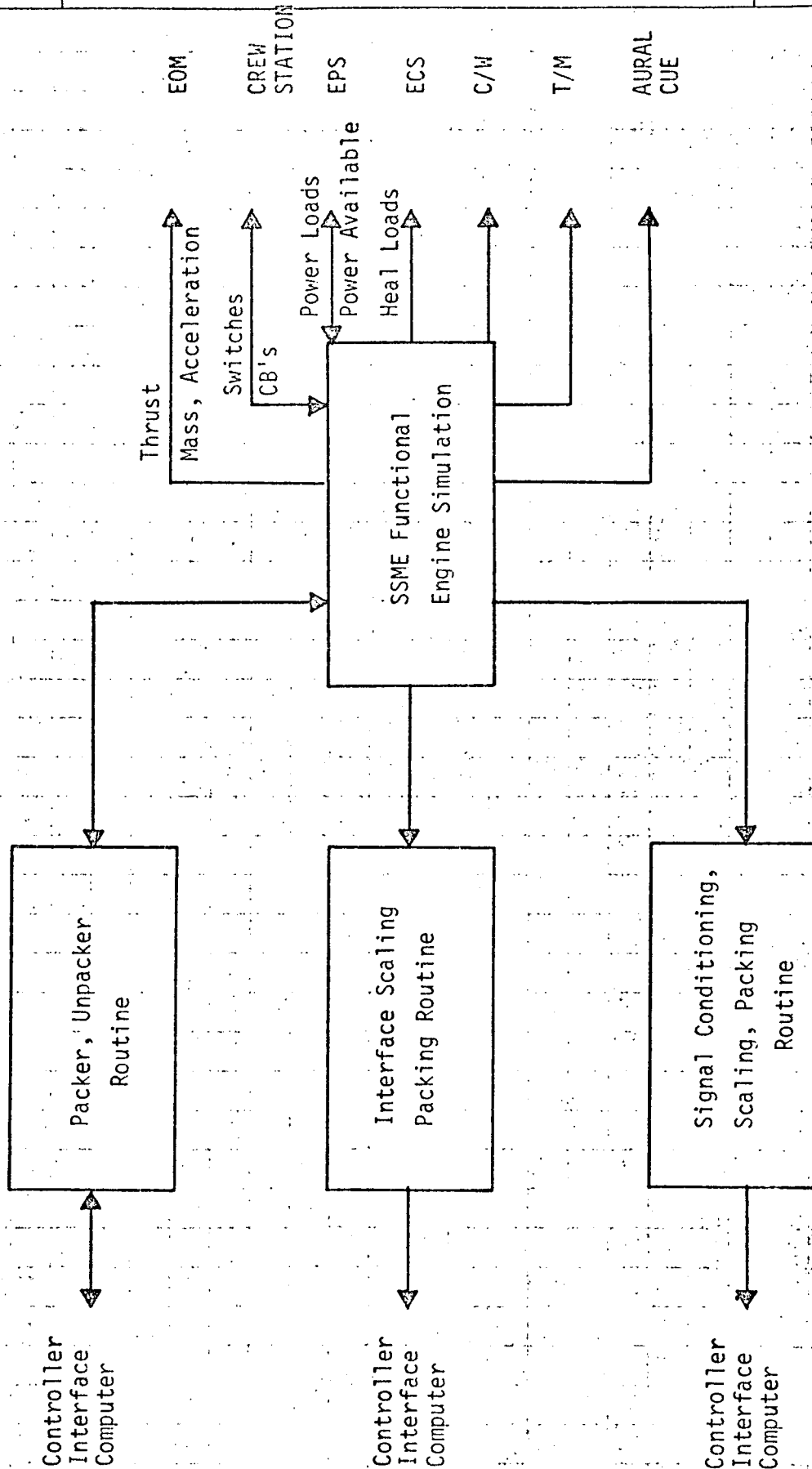


FIGURE 3.3.2.1-4
Main Engine Functional Simulation-Interfaces

This section describes the general form of equations used to represent the different processes of the SSME system. The conceptual design for the SSME simulation model has been formulated using basic process descriptions as system building blocks.

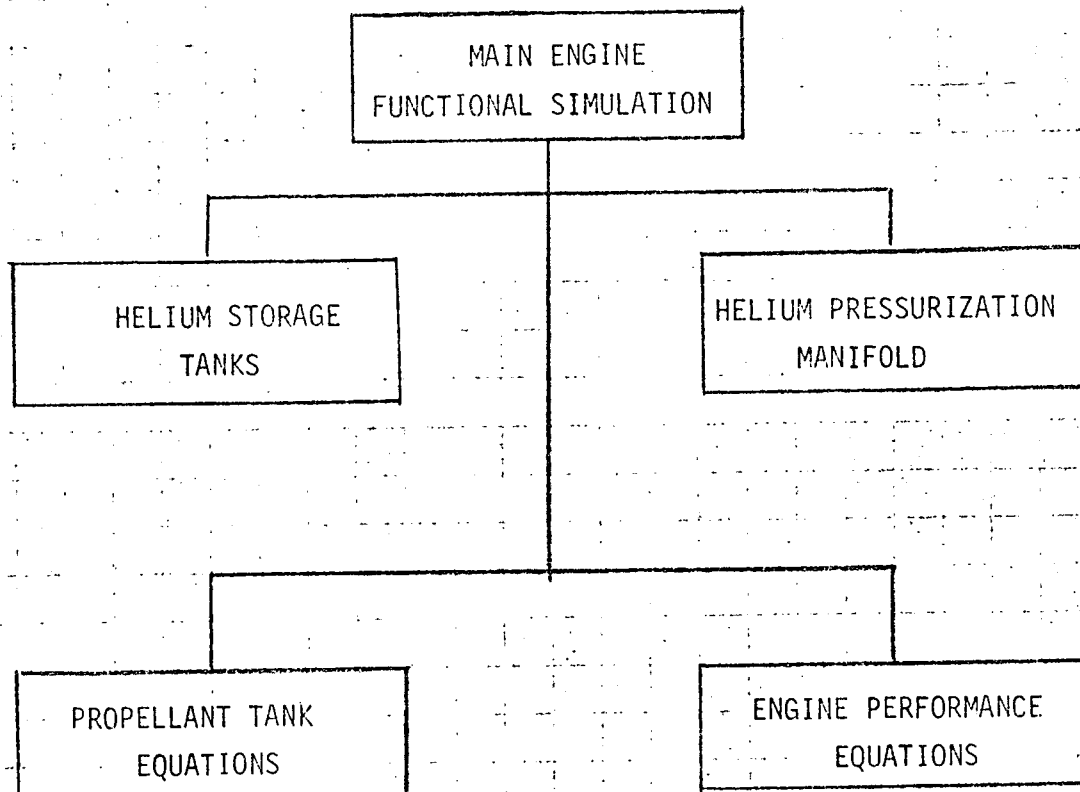


FIGURE 3.3.2.1-5

Helium Storage Tanks

A 4,000 psi helium storage system with 750 psig regulation capability is provided in the orbiter for valve actuation and engine helium requirements. During re-entry and recovery, the MPS fluid system will be repressurized with helium to preclude the entrance of contamination into the system.

The system is comprised of three storage tanks, No. 1 He, No. 2 He, and COMMON He. No. 1 Helium system is used to repressurize the LO₂ propellant system and No. 2 Helium system is used for the LH₂ system. The COMMON Helium tank provides helium to both No. 1 and No. 2 systems through a common manifold.

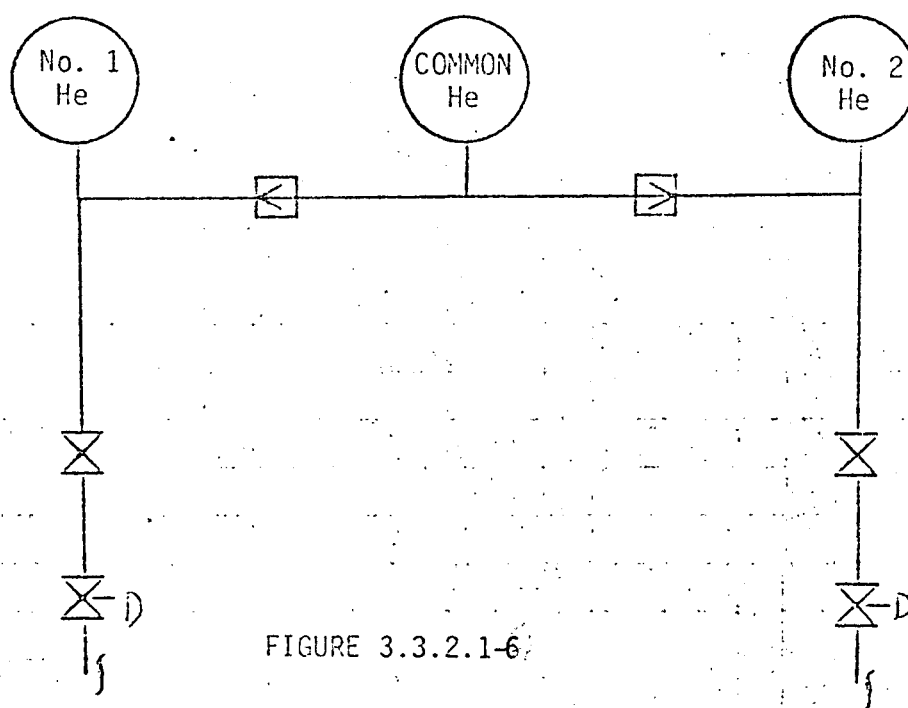


FIGURE 3.3.2.1-6

The initial gas storage pressure P_i for a tank may be expressed as:

$$P_i = \frac{R(T_i + 460)}{\left(\frac{V_t}{W_{He_i}} - \beta\right)} \quad 144$$

where: R = Helium Gas Constant - 386 ft/ $^{\circ}$ R

T = Temperature of Helium - $^{\circ}$ F

V_t = Tank Volume - Ft. 3 - Constant

W_{He_i} = Initial Helium Weight - pounds

β = Non-perfect gas correction factor - function of temperature

Initial values for Helium weight and temperature would be provided through simulator initialization (reset).

Helium weight would be computed from:

$$W_{He_n} = W_{He_{n-1}} - \int \dot{W}_{He} dt$$

Helium temperature would be computed from

$$T_{He_n} = \int \left[\frac{-(\frac{R}{J}) (T_{n-1} + 460) \dot{W}_{He} + K_t (T_a - T_t)}{C_v W_{He_n}} \right] - dt$$

where: T_{He_n} = Helium temperature - present iteration

$T_{He_{n-1}}$ = Helium temperature - last iteration

\dot{W}_{He} = Weight flowrate of helium out of tank

W_{He_n} = Weight of Helium - present iteration

J = Joules' Constant - 778 $\frac{ft - lb}{BTU}$

K_t = Effective thermal conductivity of helium tank - BTU/min - $^{\circ}$ F

T_a = Ambient temperature of Helium tank

T_t = Internal temperature of Helium tank

C_v = Specific heat of helium at constant volume - BTU/lb - $^{\circ}$ F

Helium Pressurization Manifold

Helium flowrates out of the helium storage tanks can be computed from the simplified equation for compressible fluid flow in a line having resistance, R_ℓ , measured from Point 1 to Point 2:

$$\dot{W}_{He} = \sqrt{\frac{P_1 - P_2}{R_\ell}}$$

R_ℓ is computed for each helium line and would have the units

$$\frac{\text{min}^2}{\text{in}^2 \text{lb}}$$

Simulated flowrates will be controlled by discrete logic developed to simulate valve, regulator, and helium free path conditions.

The pressure at any point, x , in the helium manifold can be computed from the pressure upstream of Point x (i.e., the regulated outlet pressure) minus the pressure drop at Point x .

$$P_x = P_{ro} - (\dot{W}_{He_x})^2 R_\ell$$

where R_ℓ is the resistance of the line from the regulator to Point x .

It is anticipated that temperature for any point in the helium manifold is not a simulation requirements since this parameter is not monitored by the flight crew.

Propellant Tank EquationsPropellant Temperature

The fuel (LH₂) and oxidizer (LO₂) temperatures will be computed from initial temperature versus time tables

$$T_{fu} = f_1(\text{time})$$

$$T_{ox} = f_2(\text{time})$$

Ullage Pressure and Temperature

The ullage pressure at any time can be expressed as a simple function of the total mass, total volume, average temperature, and average molecular weight of the tank gas, and the universal gas constant.

$$P_u = \frac{m_{tg} T_{tg} R}{V_{tg} M_{tg}}$$

The values for m_{tg} , V_{tg} , T_{tg} , and M_{tg} may be obtained at any time from the following rate equations:

$$m_{tg} = m_{tg_i} + \int \dot{m}_{tg} dt$$

$$V_{tg} = V_{tg_i} + \int \dot{V}_{tg} dt$$

$$M_{tg} = M_{tg_i} + \int \dot{M}_{tg} dt$$

$$T_{tg} = T_{tg_i} + \int \dot{T}_{tg} dt$$

The parameters which generally experience the greatest change and therefore, have the greatest effect on the tank pressure are the gas mass and volume. The change in the mass of pressurizing gas is obtained from

the flowrates of any gases entering or leaving the tank, plus any mass transfer between liquid and gas phases in the tank. The change in gas volume is equal and opposite to the change in liquid volume in the tank. The change in liquid volume is primarily due to propellant outflow to the engines, but also includes the effects of propellant mass transfer and density changes.

The changes in tank gas temperature depend on the energy balance for the total tank gas. The energy terms involved in the balance are related to a number of possible factors:

1. Specific enthalpy and flow rate of the entering gas.
2. Mass transfer between gas and liquid phases.
3. Heat transfer between gas and liquid phases and between gas and tank wall.
4. Change in internal energy of the gas phase.
5. Expulsion work on the propellant

$$\dot{T}_{tg} = \left[\frac{\sum \dot{Q}_g + \sum h_{ge} \dot{m}_g + \sum h_{gv} \dot{m}_{gv} - \sum \dot{m}_g u_s - \frac{P_{ts} \dot{V}_{tg}}{J}}{\sum \dot{m}_g C_{vs}} \right]$$

where: \dot{Q} = heat quantity rate

h = specific enthalpy of tank gas

\dot{m} = mass flowrate of gas

u = specific internal energy

p = pressure of tank gas

\dot{V} = rate of change for ullage volume

C_v = specific heat capacity at constant volume

Subscripts:

g = ullage gas

e. = entering

v. = vaporization

t = tank

The solutions to the equations for \dot{m}_{t_s} , \dot{v}_{t_s} , \dot{M}_{t_s} , and \dot{T}_{t_s} require a knowledge of the thermodynamic properties of the gases concerned, the heat transfer rates, mass transfer rates, in-flow rate and temperature, and the out-flow rates.

Propellant Densities

Using the temperature and tank ullage pressure, the density of each propellant can be determined from the following expressions:

$$\rho_{ox} = f(P_{ox}, T_{ox})$$

$$\rho_{fuel} = f(P_{fuel}, T_{fuel})$$

Propellant Volume

The volume of propellants in the tanks is computed from the remaining weights and liquid density.

$$V_{fuel_t} = \frac{W_{fuel_t}}{\rho_{fuel}}$$

$$V_{ox_t} = \frac{W_{ox_t}}{\rho_{ox}}$$

Propellant Tank Volume

The total volume should be the volume of the tank under use conditions, i.e., tank stretch due to the internal pressure should be considered, and tank shrinkage due to the cryogenic propellants should be included.

$$V_T = V_C + \Delta V_P + \Delta V_{TEMP}$$

where:

V_T = Total tank volume under use conditions

V_C = Total tank volume at Opsig internal pressure and ambient temperature

ΔV_P = Change in total volume due to internal pressure

ΔV_{TEMP} = Change in total volume due to temperature

The tank ullage volume can be computed from:

$$V_{ULLAGE} = V_T - V_{PROP}$$

Acceleration Head

The vertical distance from the propellant levels in the tanks to particular levels of interest in the feed system is required (due to vehicle acceleration) in the calculation of pressures. The levels of interest in the simulation are the liquid levels, tank bottoms, engine feed system, interface, and thrust chamber. The heights from tank bottom to interface (HIT) and interface to thrust chamber (HCI) are considered, being dictated by MPS dimensions.

Tank Liquid Levels

The levels will be determined using height-volume tables. The volumes used will be the volume of all of the oxidizer or fuel left in the propulsion and feed system.

$$H_{fuel} = f(V_{fuel_t})$$

$$H_{ox} = f(V_{ox_t})$$

Total Height - Tank Liquid Level to Chamber

$$HCLFU = H_{fuel} + HIT + HCI$$

$$HCLOX = H_{ox} + HIT + HCI$$

Height - Interface to Injector Inlet

$$HLIFU = H_{fuel} + HIT$$

$$HLIOX = H_{ox} + HIT$$

Pressure at Bottom of Propellant Tank

$$P_{tb} = \frac{P_{tg} + (H_{prop})(\ddot{X}_{body} + G_{x_b})\rho_{prop}}{144g}$$

where: P_{tb} = Pressure at bottom of propellant tank

P_{tg} = Ullage Pressure

H_{prop} = Height of Propellant in Tank

\ddot{X}_{body} = Vehicle Acceleration along X body axis

G_{x_b} = Earth's gravitation along x body axis

ρ_{prop} = Density of propellant as a function of ullage pressure and temperature

g = Gravitational constant - 32.2 feet/second²

Engine Equations

Propellant flow rates can be based on the Bernoulli equation:

$$\dot{W}_{\text{prop}} = \sqrt{\frac{1440(P_1 - P_2)}{R}}$$

where: P_1 = Inlet pressure - psi

P_2 = Outlet pressure - psi

ρ = Propellant Density - lbm/ft³

R = Flow resistance - lb_f sec²/lb_m ft⁵

Flow Rate Relations

$$\text{Mixture ratio} = MR = \dot{W}_{\text{ox}} / \dot{W}_{\text{fuel}}$$

$$\text{Total Propellant Flowrate} = \dot{W}_T = \dot{W}_{\text{ox}} + \dot{W}_{\text{fuel}}$$

Engine Performance Equations

The engine performance equations for the SMS SSME simulation should be based on the digital simulation prepared by North American Rockwell Corp. This digital simulation for the SSME is described in NAR document RL00001, Rev. B. This approach should allow for the most convenient modification to the SSME simulation upon receipt of NAR change data and should provide for efficient correlation of simulator performance with NAR predicted, or actual performance, data for the SSME.

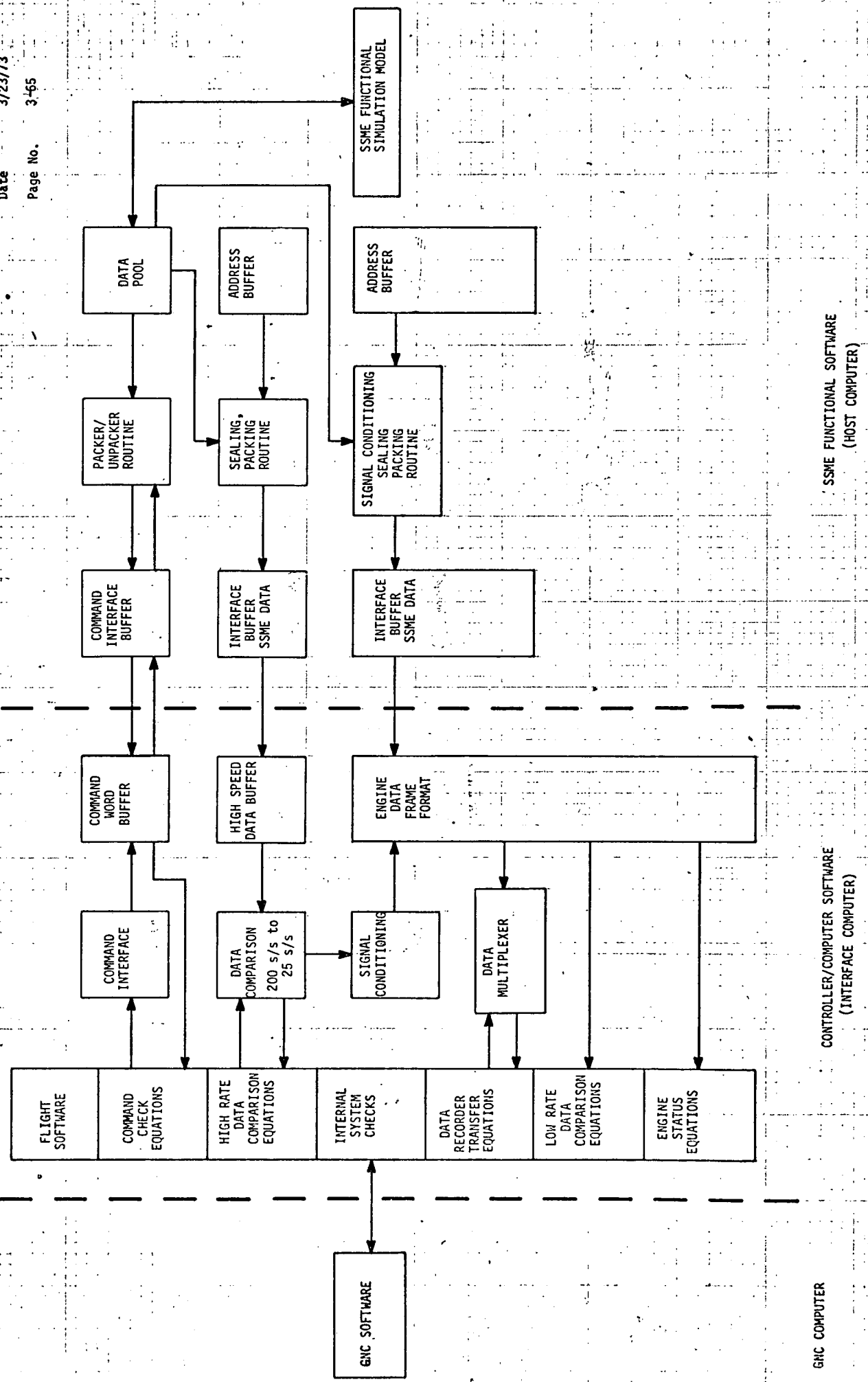
Main Engine Controller SimulationConcept 1- Flight Software Simulation

A translative type flight program appears as a possible working solution to the digital-analog interface simulation. Since the analog function is continuous and the digital interface function is by cyclic steps, a problem is created by the differences in the two computer basic program cycles.

Figure 3.3.2.1-7 shows the proposed interface structure between the three computer groups; GNC, Controller/Interface, and the host computer. In the translative approach, the interface between the GNC computers and the engine controller/interface computer presents no particular problem of timing or data rate of computation because the proposed computers parallel the real world installation.

The simulation of the controller functions by the actual flight software may be accomplished by furnishing the required inputs and outputs at the required data rates. Use of the flight software in a separate computer which can function the same as the real world HDC601 solves the major interface problems of command and response between the GNC computer and the controller computer. The remaining interface problem is between the controller computer and the functional main engine simulation computer. Since in the real world the controller would normally interface with analog type inputs and outputs, provision must be made in the controller computer to accept digital coded data. For outgoing commands DCE is also not required because of the digital interface.

FIGURE 3.3.2.1-7 SSME SIMULATION INTERFACES
(Typical 1 of 3)



In the interface between the controller computer and the host computer, the software buffer areas and equation requirements are shown. The commands from the GNC computer may require minor processing both before and after computation in the flight software program. Within the host computer the difference between computer word lengths (16 bits and 32 bits or 36 bits) requires an unpacking routine to separate the interface buffer of 100 words (estimated) into the original 200 commands.

The analog engine performance data in the real world that is sampled at rates of 25, 50, 100, and 200 samples per second must be simulated to supply the controller computer with values which will not cause the program to go into a malfunction mode during nominal simulated operating conditions. This approach must also allow for malfunctions which, when sensed, cause the controller computer flight software to respond similar to the real world system. An approach to the solution of the controller interface for the high rate data problem is during the intermediate computation cycles to use the controller calculated values rather than functionally generated values for the iteration parameter monitoring. This approach is allowable because the engine simulation response is ideal (no malfunctions) and the controller calculated value would equal the functional value if the functional model were to be executed at that point in time. Malfunctions in the engine model which would cause deviation from the ideal value can be included in the software within the interface co-puter. The controller computer instruction used to initiate the analog-to-digital conversion of the parameter could be translated into a signal to execute a routine to transfer the data word used for comparison into the expected D/A address, or to enter a malfunction value based on system condition, or to enter the functional simulated value.

This process would cause the present calculated value to possibly be compared to the past calculated value dependent on the arrangement of the flight software statements.

It is to be noted that under this approach no modification to the flight software is required, with the possible exception of the executive control for the interface computer and the translative instruction for transfer.

This approach is shown in a graphic manner in Figure 3.3.2.1-8. The bottom of the bar/figure represents the controller computer program and its cyclic rate of sampling data at 100 samples/second. The top of the bar/figure represents the main computer program and its cyclic rate of main engine data simulation at 20 samples/second. Case 1 shows a comparison where the parameter value calculated in the main computer is compared to the predicted value in the controller computer. On the following machine cycle of the controller computer, the main computer will not have updated the engine parameter values. The cue to input the DCE in the normal flight software could indicate that a new value of data should be entered. At point 2 the comparison would be made then by using the last predicted value of the parameter as a test for the value predicted at this time point. The values will be in the tolerance limits of the flight software because of rate limiting. This condition will repeat until the main computer updates the functional value. At that update, the functional value would be loaded rather than the predicted value for comparison purposes. A malfunction when entered into the main computer would be transferred over the interface to cause simulation of malfunctioning parameters, instrumentation or signal conditioning. On the cycles following the transfer, the malfunction parameter value would cause the

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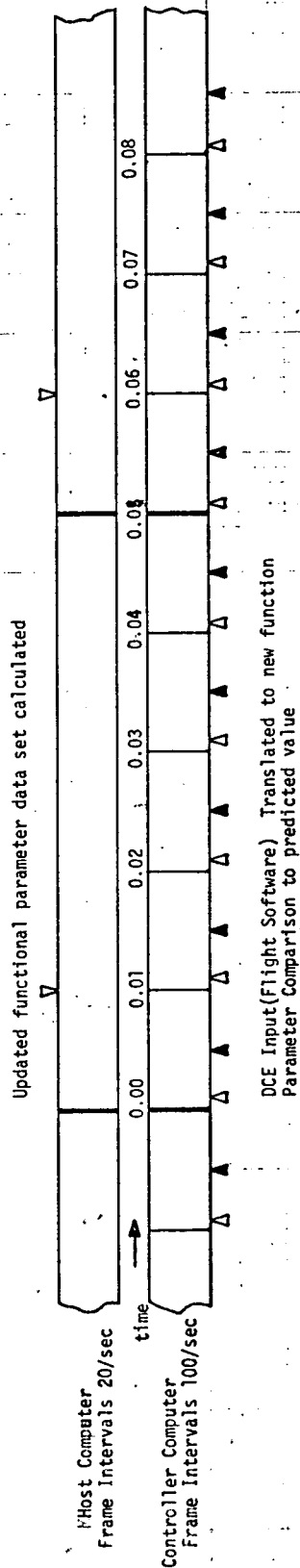


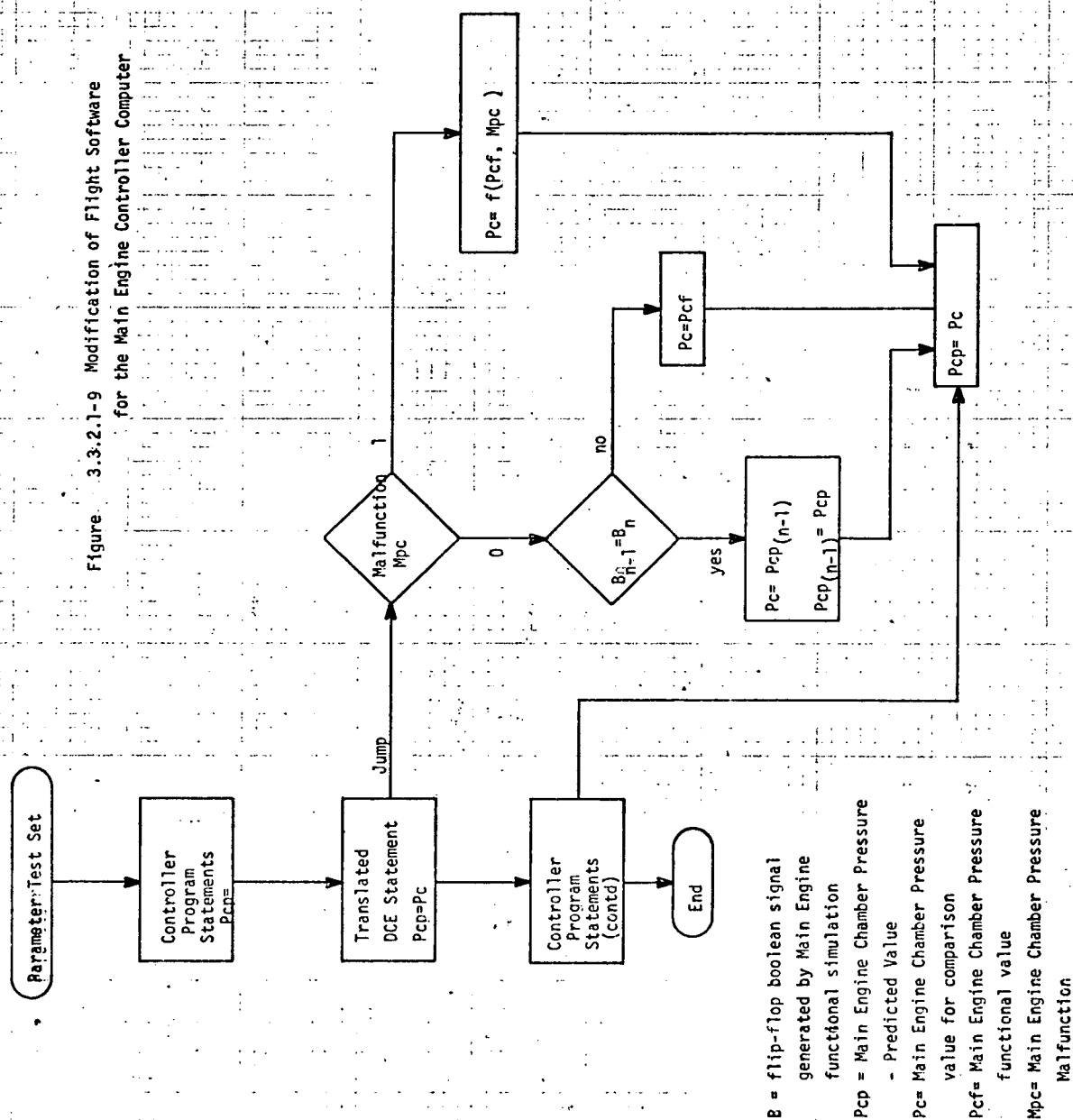
FIGURE 3.3.2.1-8
Interface of Low Speed Functional Data to High Speed Controller Comparison

controller computer to react identical to a real world situation.

This process is shown in Figure 3.3.2.1-9.

Data generated by the host computer for performance monitoring at rates of 5 per second and 1 per second require minor conversion to be compatible to the controller flight software. Instrumentation signal conditioning power available booleans need to be checked for the measurements and the computer word converted from a floating point number to fixed point with a scale range limit imposed. The limit is defined in the table for flight data. In addition the host computer words require packing into a sixteen bit word format prior to transmission. Because of the rate differences in the two computers, a 600/1200 word buffer, or one full second of simulated data, is transmitted to the interface computer. This provides a buffer area that is suitable for direct insertion of the higher rate data parameters without reformatting the data into a secondary buffer. The data may then be multiplexed by selection of the buffer section which corresponds to the controller frame cycle. NOTE: The buffer provides one second of data divided into twenty-five distinct sections matching the real world multiplexer format as previously described.

Figure 3.3.2.1-9 Modification of Flight Software
for the Main Engine Controller Computer



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CONCEPT 2 - Functionally Simulated SSME Controller

This concept is basically a functional model of the real world system described in North American Rockwell Document RC1010 Computer Program Requirements - Controller, Revision C. This real world description was modified to consist only of the interfaces required either by the GNC Computer or the functional Main Engine Simulation. Redundancy testing for malfunctions (which in the simulated world are controlled entries) and internal logic testing was deleted to reduce the program software requirements.

The computer programs defined by this specifications are ordered sets of instructions and data required for the operation of the functionally simulated Space Shuttle Main Engine (SSME) Controller Computer. These programs shall be the SSME Controller software necessary to control the functionally simulated SSME during Shuttle Mission Simulator (SMS) operation.

Specific computer programs which will accomplish this stated control objective are defined in the following paragraphs.

Controller Program - The Controller Program will be used for control of functionally simulated SSME operation during all phases of SMS operational use. A typical operational mission sequence is shown in Figure 3.3.2.1-10. This sequence is characterized by the successive occurrences of different engine operating phases. Each phase is characterized by the type of control functions which are occurring. These phases and characteristic functions are as follows:

(a) Checkout - Includes preflight calibration of pressure sensors and a simulated start and shutdown sequence, without propellants in the engine system.

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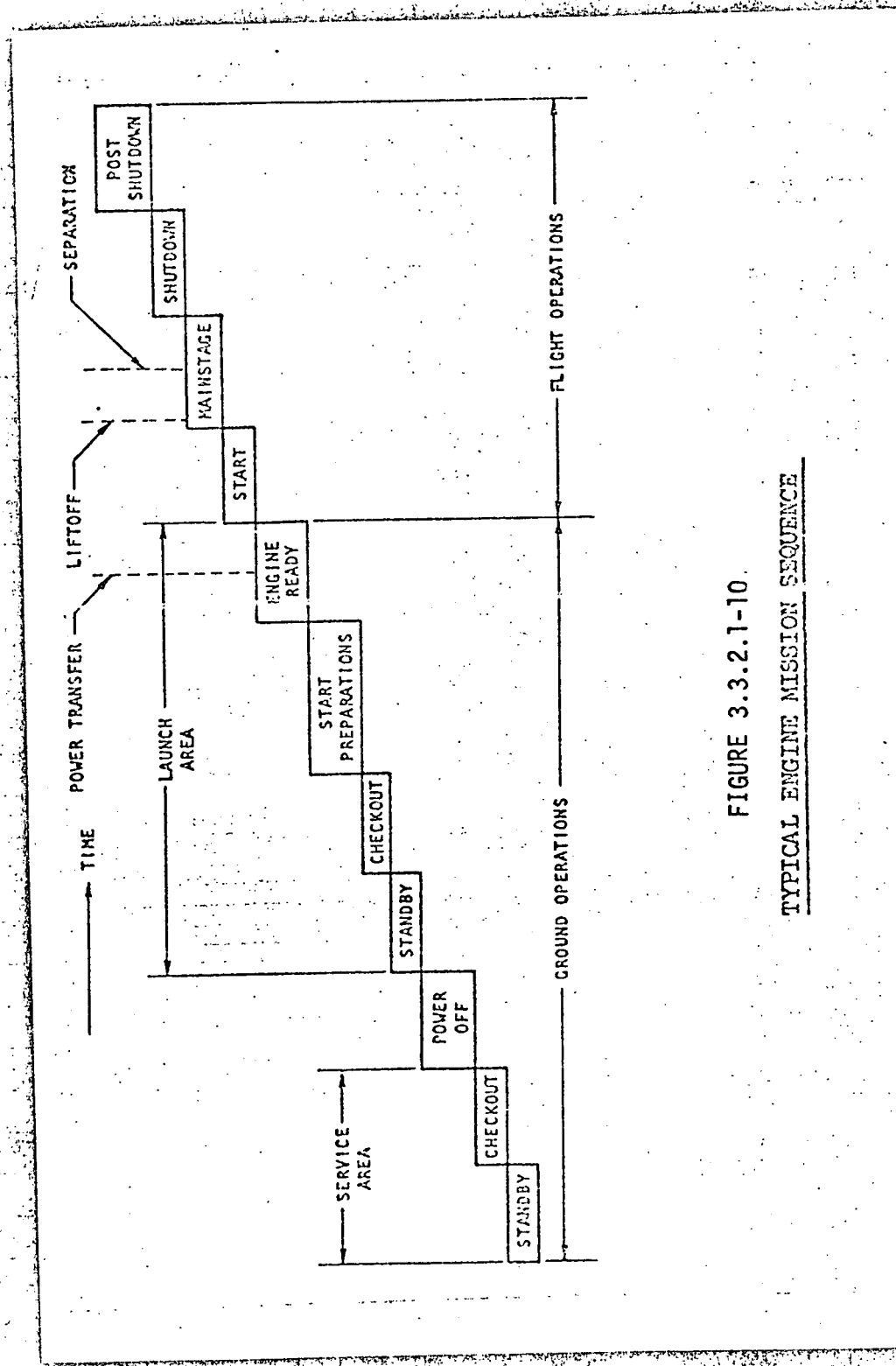


FIGURE 3.3.2.1-10

TYPICAL ENGINE MISSION SEQUENCE

(b) Start Preparation - Includes functions required to condition the engine for starting such as purging and control of propellant recirculation.

(c) Start - Functions required to start and sequence the engine to mainstage are included such as valve sequencing, ignition, and thrust buildup control.

(d) Mainstage - Encompasses functions required for continuous performance control in the mainstage power range which is between 50 percent and 109 percent of normal power level (NPL).

(e) Shutdown - Includes functions required to shutdown the engine such as thrust decrease ramp control, and programmed closing of valves.

(f) Post Shutdown - Normally a quiescent standby stage of control operation except for controller self test functions which occur continuously whenever power is on. Optional functions of propellant dumping or abort turnaround are possible during this phase.

During all phases of operation the Controller Program performs data processing functions for failure detection and status data supplied to the vehicle.

As system operation progresses through an operating phase, different combinations of control functions are operative at different times. These different operating combinations within a phase are defined as operating modes.

As an example, the Mainstage phase has the following operating modes:

Normal Control

Thrust Limiting

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Operating mode definitions for all phases are given in Table XIX. Operational program functions, their sequencing and timing will later be related to the phases and modes of system operation.

Because some functions are performed in more than one operating phase or mode the logic required for operational control of the functionally simulated SSME shall be divided into several groupings of functional logic which in combination are capable of performing all logical operations required for control of the SSME.

This specification presents a set of Functional Elements which define the requirements of the Controller Software. This has been done to more clearly present functional requirements of the program and to show the interrelation between these requirements. The Controller Program end product shall be made up of a set of subprograms called Computer Program Components (CPC's). Organization of the Operational Program into specific CPC's to coincide with the organization of the Functional Elements as presented in this specification is not a requirement. However, the resulting program must accomplish the functions and meet the performance requirements of this specification.

Controller Program Definition - The Controller Program shall satisfy the requirements of the nine Functional Elements shown in Figure 3.3.2.1.11. These Functional Elements are defined in the following subparagraphs.

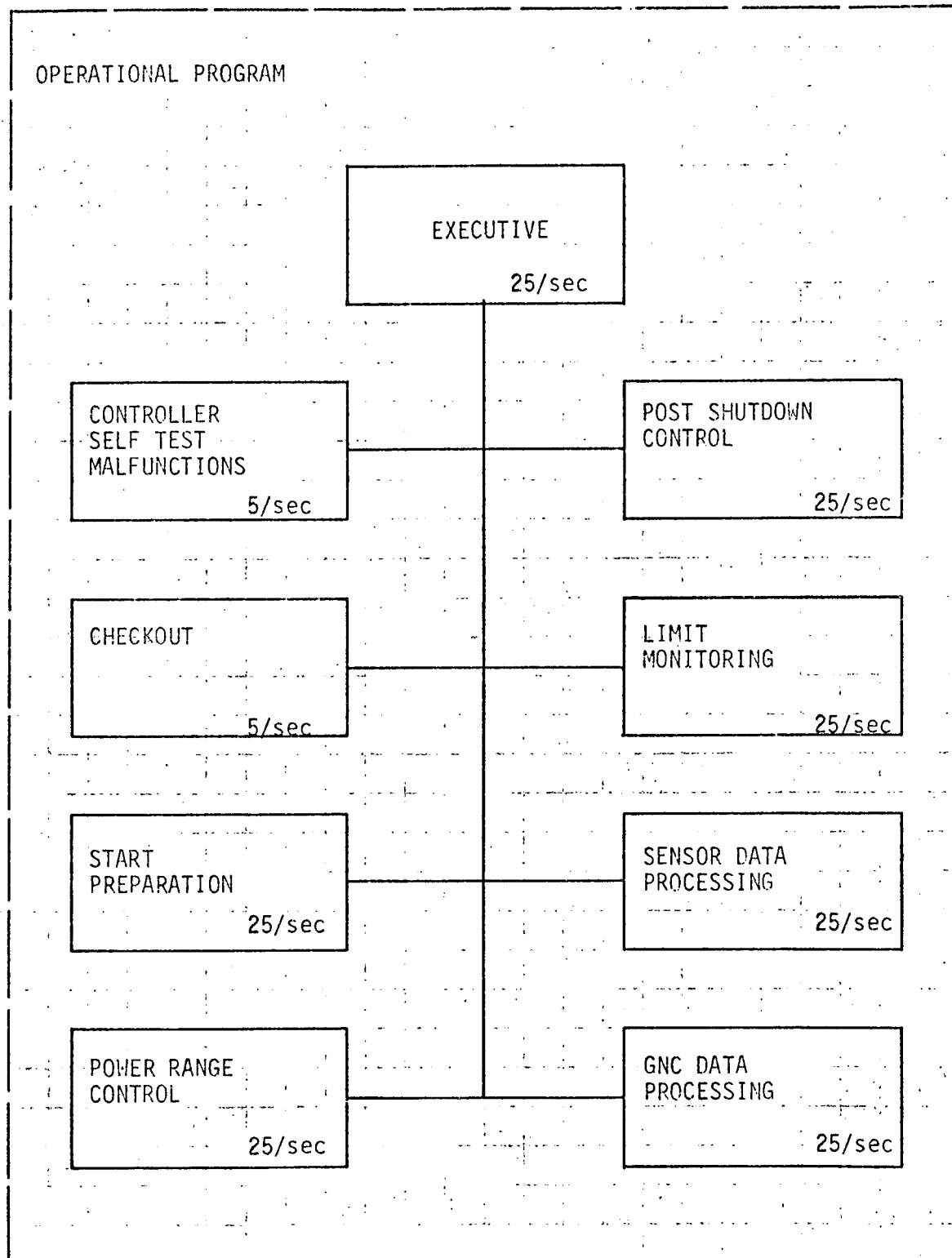


FIGURE 3.3.2.1-11

OPERATIONAL PROGRAM FUNCTIONAL ELEMENTS

Executive Functional Element - This functional element establishes the sequence of operations to be performed by the controller software. Operation of the Executive Functional Element is cyclic. Under normal operation, whether on the ground for checkout or during flight, the controller computer progresses through the Executive Functional Element performing program logical operations in an endless loop (25/sec). Each loop through the functional element is called a major executive program cycle. The loop may be revised by any one of several types of events which cause an interrupt in the existing sequence:

- (a) Command received from GNC alters a phase or mode of operation.
- (b) A built-in test program determines component malfunction.
- (c) Engine limit detection monitor determines an engine limit has been exceeded.

The Executive Functional Element contains the logic to evaluate all of the three events listed, update engine status information supplied to the GNC and change the combination of subprograms being processed by the computer.

Controller Self Test Functional Element - This functional element is executed once during every 5 major executive program cycles. It verifies the status of all controller components. If a component malfunction which does not impair the operability of the controller is detected, the malfunction is indicated and the next step normally performed in the test sequence is executed. If a malfunction occurs which results in an inoperative controller channel, the malfunction is indicated and control is transferred to the Executive Functional Element for the processing of channel shutdown.

Checkout Functional Element - This functional element performs preflight calibration of specified performance control sensors. A simulated start and shutdown sequence is also provided to verify the operation of some sensors, engine control components, without propellants in the engine system.

Start Preparation Functional Element - This functional element controls system purges and propellant conditioning during preparation for engine start. It also verifies propellant conditions prior to indicating an Engine Ready status for start.

Four sequence conditions are required to condition the engine for start. These include: (1) GN2 (gaseous nitrogen) purge of oxidizer system and HPOT (high pressure oxidizer turbopump) Turbine Seal until engine start and helium purge of HPOT Intermediate Seal; (2) helium purge of the fuel system prior to dropping propellants; (3) propellant recirculation when propellants are dropped; and (4) helium purge of the fuel system repeated prior to engine start. The time allocated for each purge is controlled by the vehicle. Interlocks in the software program verify that the sequence is correct and that conditions are acceptable prior to initiating each purge. Correct purge pressure conditions are verified each major cycle of the Executive Functional Element.

Power Range Control Functional Element - This functional element controls engine operation during the start, mainstage, and shutdown phases of engine operation.

During start, valve positions are sequenced and programmed, igniters are energized, ignition verified, and closed loop thrust and mixture ratio control is initiated.

In the Mainstate Phase, engine thrust and mixture ratio are controlled to reference levels supplied from the GNC. The thrust and mixture ratio control perform dynamic compensation functions on feedback sensor signals, conditioning of reference signals for rate of change and limits, computation of performance errors and control compensation of derived errors to provide control valve position reference signals. Closed loop temperature limit control functions are also performed.

Thrust decrease programming and valve sequencing functions are performed during the Shutdown Phase. Logic is also provided for Limit Shutdown or Emergency Shutdown from any thrust level.

Post Shutdown Control Functional Element - This functional element contains control logic for the engine during the Post Shutdown phase of engine operation. Three types of operational modes are controlled by the logic and may be selected by vehicle command. These are:

- (a) Standby
- (b) Propellant Dump (Oxidizer Dump and Fuel Dump Modes)
- (c) Abort Turnaround (Sequence No. 1 & Sequence No. 2 Modes)

Standby - This is a waiting mode of controller operation normally entered at the completion of the Shutdown phase. In this mode only the Executive, Sensor Data Processing, GNC Data Processing, and Controller Self-test Functional Element operations are being performed.

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Propellant Dump - The propellant dump modes of operation sequences valves and provides interlocks for safe control of propellant dumping. The duration of dumping for each propellant is controlled by the GNC. Separate commands are required from the GNC to initiate oxidizer dumping, then fuel dumping, and terminate the process.

Abort Turnaround - The abort turnaround modes of control are a modified Start Preparation sequence used to prepare the engine for start shortly after an aborted firing. The sequence timing is controlled by the GNC. Logic is provided to ensure that a proper sequence is performed and that conditions are correct before an Engine Ready Status signal is given.

Limit Monitoring Functional Element - This functional element checks limit shutdown parameters and actuator position errors against specified limits relative to the phase operating requirements. Unsatisfactory status conditions are identified for evaluation and corrective action.

The Limit Monitoring Functional Element is operative every major executive program cycle. During all operational phases propellant valve position commands and indicated positions are compared to verify correct positioning. Monitoring functions for other system parameters occur during flight operation. These functions vary according to the operating phase and status within the phase.

Sensor Data Processing Functional Element - This functional element is active every executive program cycle. It scales raw data from sensors with redundant channels. Scaled values are obtained by using calibration constants stored in memory. Status on malfunctioned sensors is indicated. This functional element also processes scaled sensor measurements to produce propellant weight flow rates, engine mixture ratio, and thrust level data for control and engine maintenance recording.

Vehicle Data Processing Functional Element - This functional element is operative during all phases. It processes engine status, performance and maintenance trend data to the proper format required for transmission to the vehicle.

Program Interface - As shown in Figure 3.3.2.1-12 data flow to the Controller Functional Program comes from GNC commands, controller elements and engine system sensors through the GNC/Engine and Controller/Engine Interface. The Controller Program produces status information and performance data which is transmitted to the GNC through the GNC/Engine Interface. The Controller Program also produces control command signals which control engine functions through the Engine/Controller Interface.

GNC/Engine Data Interface - The Controller Program provides for accepting and responding to GNC commands. The format of GNC commands transmitted via the GNC/Engine Command channels to the controller shall be as defined in Table IV. The format of data transmitted from the controller via the GNC/Engine Recorder channels every data transmission cycle (every 40 ms) shall be as defined in Table VI. Data transmitted from the controller via the GNC/Engine Command channels in response to a Status Request command shall be as defined in Table V.

Controller - Engine Data Interface - The Operational Program provides for accepting engine sensor data and producing control signals. See Tables IX, I and II for sensor ranges, temperatures limit control range and engine limit control shutdown parameter.

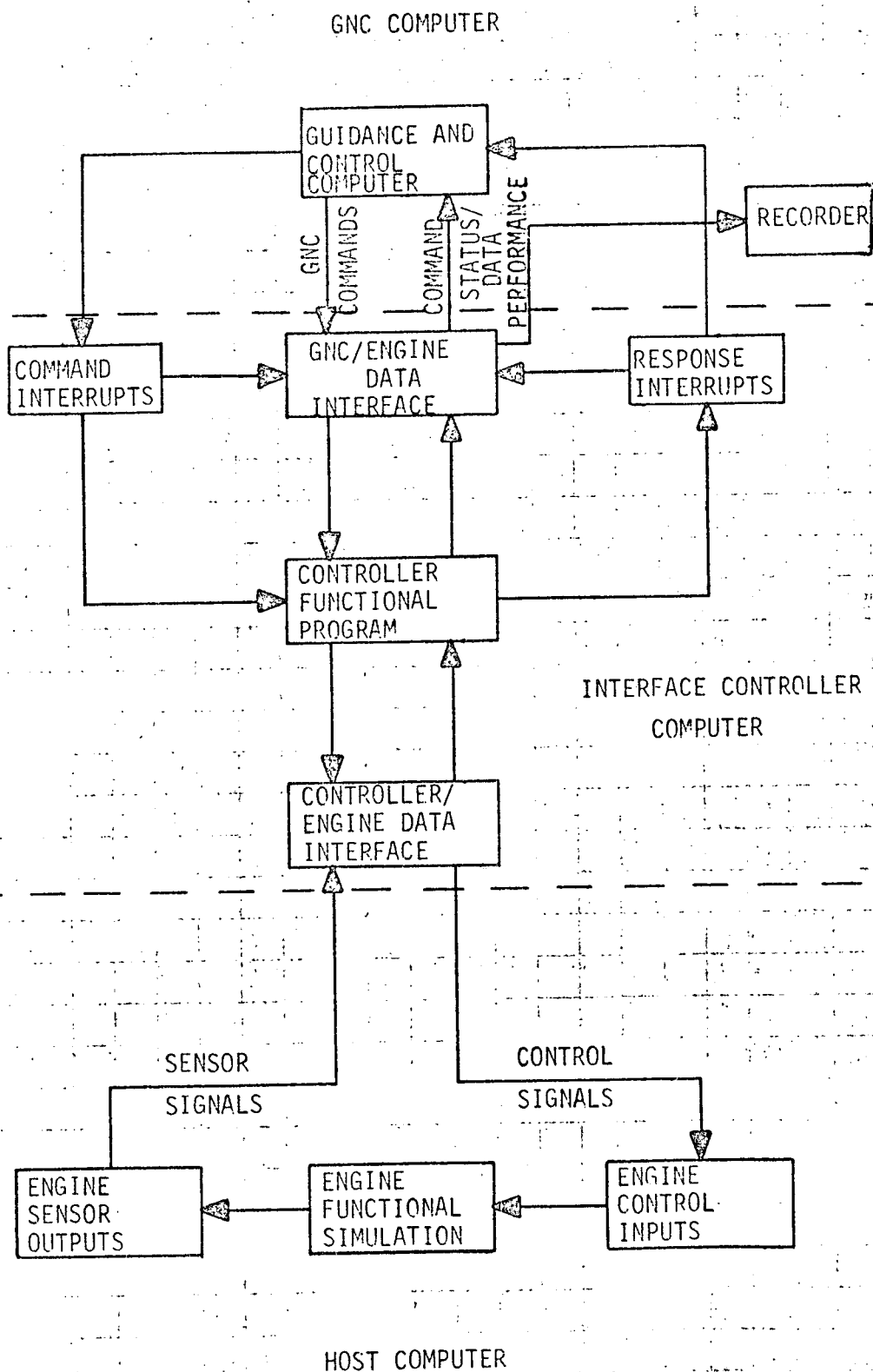


FIGURE 3.3.2.1-12

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Performance of Controller Software

Executive Functional Element - The Executive Functional Element shall control Controller Program sequencing and perform logical operations so that the following operational requirements are satisfied.

Engine Status - Engine status information, defined in Table V, shall be computed and updated every major executive program cycle (25/sec). This information shall be available for transmission to GNC upon receipt of a Status Request command. This required status information, supplemented as necessary by additional status information computed solely for program use, shall be used in conjunction with logic to validate (accept or reject) GNC commands and establish sequencing and interlocking of controller functions.

GNC Command Processing - The Executive Functional Element shall receive commands in the format defined by Table VII from all operable GNC/Engine Command channels. Any single command channel shall be disqualified from GNC command processing by any one of the following commands from GNC: Command Channel 1 Inhibit, Command Channel 2 Inhibit or Command Channel 3 Inhibit. The inhibit to any command channel shall be removed by any one of the following commands from GNC: Command Channel 1 Enable, Command Channel 2 Enable or Command Channel 3 Enable. Command words from GNC, to disqualify and restore command channels, shall be via the remaining operational command channels.

GNC commands shall be of two types: absolute commands and variable commands. The variable commands are Thrust Level and Mixture Ratio. All other commands are absolute commands.

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GNC Command Validation - Commands from the GNC shall be validated or rejected by command channel voting and agreement with engine operating phase.

Command Channel Voting - Absolute commands shall agree exactly in content for all operable command channels. Variable commands shall agree within (TBD) percent of each other if all three command channels are operative, and (TBD) percent if only two channels are operative. For operation with three good channels, two out of three agreement constitute a good vote. For two good channels, both channels must agree in order to constitute a good vote. Failure to obtain a good vote shall result in a Message Reject Code to be transmitted to the vehicle.

Command Agreement with Phase - After a command has been validated by command channel voting, the command shall be checked for agreement with engine phase of operation in accordance with Table IV and the requirements (a) through (f) below. If a command is determined to be invalid due to disagreement with engine phase or mode of operation, a Message Reject code shall be transmitted to the GNC.

(a) Checkout Phase - This phase of operation may be entered upon initial power on, or from the Start Preparation or Post Shutdown phases subsequent to the receipt of a Controller Reset Command. There shall be no restrictions on switching between functional modes of this phase.

(b) Start Preparation Phase - This phase shall be entered only if checkout is complete. GNC start preparation phase commands received during this phase shall not be implemented if they are not in normal sequence or within the time limits specified in "Start Preparation Functional

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Element". The Start Preparation phase sequence may be started over provided criteria for start of the phase are still satisfied.

(c) Start Phase - This phase shall be entered only if Engine Ready status conditions are satisfied and all Start Preparation or Abort Turnaround procedures have been completed. GNC Limit Control Inhibit commands shall be ignored until ignition has been confirmed.

(d) Mainstage Phase - This phase is entered from the Start phase without a GMC command.

(e) Shutdown Phase - Once initiated it shall not be possible to initiate a new phase until all functions of this phase have been completed. Only the Post Shutdown phase may be entered after the Shutdown Phase.

(f) Post Shutdown Phase - This phase shall be entered only after the Shutdown phase.

Implementation of Vehicle Commands - All commands from the vehicle, except the Status Request command, shall be implemented after a Command Execute command has been received and validated. A validated command shall not be implemented if a command other than Command Execute is subsequently received.

Command Failure Identification - When a Message Reject code is the result of GNC command processing, then the failure identification code for Invalid GNC command shall be inserted in the failure identification word and the failed parameter word shall contain the rejected command code.

When a failure which can be isolated to an individual command channel is detected by command channel voting, then the failure identification code for one of the GNC/Engine Command Channels shall be inserted in the failure identification word. The test number word shall contain the number of times a fault has been isolated to that channel and the failed parameter word shall contain the command as received on that channel. When a failure has been verified for three successive commands from the GNC on any single command channel, then that channel shall be disqualified from future GNC command processing until a Command Channel Enable command is implemented for that channel.

Malfunctions - The Executive Functional Element shall receive and respond to failure status indications in accordance with Table XII.

Cycle Time - The Executive Functional Element shall complete a computational cycle at least every 40 milliseconds.

Response to Interrupts - The Executive Functional Element shall include the capability to respond to program interrupts caused by but not limited to:

- (a) Controller Failure
- (b) Servovalve Redundancy Failure
- (c) Vehicle Command

Controller Self Test Functional Element - This functional element shall verify the status of all controller components except components which are checked as part of the sensor input tests of the Sensor Data Processing, and Checkout Functional Elements. Self test shall be performed every five major executive program cycles. All malfunctions will be monitored in this program.

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Checkout Functional Element - This functional element shall perform Preflight Calibration, a simulated start and shutdown sequence and other operations associated with the Checkout phase of engine operation.

Checkout Conditions - Upon receipt of a Controller Reset command the Operational Program shall be initialized as follows:

- (a) The Engine Status Word shall be set to the Standby mode of Checkout and to indicate Engine OK.
- (b) All failure indications shall be reset to indicate no failures.
- (c) All propellant valves shall be commanded closed.
- (d) All solenoid and torque motor coils shall be de-energized.
- (e) All disqualified component channels shall be restored to normal operation.
- (f) All I responses as defined by Table XII and their overrides shall be reset.
- (g) Checkout Complete and Engine Ready Status shall be negated.

Verification of No Propellant Drop and Hydraulic System Pressure, and Flowmeter Spin Limit Control shall be performed every major executive program cycle during the Checkout phase. Executive, Controller Self-Test, Sensor Data Processing and Vehicle Data Processing operations applicable to the Checkout mode shall be continuously active during this phase. The actuator fail-safe coils and the Emergency Shutdown Control Valve Coil shall be de-energized during Checkout, except where energization of these coils are

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necessary to perform checkout requiring hydraulic actuation of the propellant valves or to checkout the Emergency Shutdown control system.

Start Preparation Functional Element - This functional element shall control system purges and propellant conditioning during preparation for engine start. It shall also verify that satisfactory conditions exist for Start prior to updating of the Engine Status Word to Engine Ready. Propellant valves shall remain closed, igniters shall remain off and the measured hydraulic pressure shall remain within tolerance.

The initiation and duration of each purge is controlled by GNC command. A specified set of operations shall be performed upon the receipt of each purge command from the GNC. Functions performed in response to each GNC command are defined and given in their normal sequence in the following subparagraphs.

Purge Sequence No. 1 (Oxidizer System-High Pressure Oxidizer Turbo-Pump (HPOT) Turbine Seal and Intermediate Seal Purges - The operations associated with this sequence are initiated after validation of a Purge Sequence No. 1 command from the GNC. Operations of this sequence are defined in Table XIII Part A.

Purge Sequence No. 2 (Fuel System Purge) - GNC commands for initiation of this sequence shall not be accepted unless the operations of sequence No. 1 have been accomplished and at least 4 minutes have elapsed since the initiation of sequence No. 1. After receipt and validation of a Purge Sequence No. 2 command from the GNC the operations of Table XIII Part B shall be performed.

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Purge Sequence No. 3 (Propellant Recirculation) - GNC commands for initiation of this sequence shall not be accepted unless the operations of Sequence No. 2 have been accomplished and at least 3 minutes have elapsed since the initiation of Sequence No. 2. After receipt and validation of a Purge Sequence No. 3 command from the GNC the operations of Table XIII Part C shall be performed.

Purge Sequence No. 4 (Fuel System Purge After Propellant Drop) - Commands for this sequence shall not be accepted until 27 minutes have elapsed from the initiation of Purge Sequence No. 3. After validation of a Purge Sequence No. 4 command from the GNC the operations of Table XIII Part D shall be performed.

Engine Ready Conditions - An Engine Ready status signal shall be provided to the GNC at the completion of engine conditioning for start if conditions are correct. The following conditions must exist for an Engine Ready status signal to be provided to the GNC.

- (a) All propellant valves must be closed.
- (b) Hydraulic system pressure must be within the same tolerance band as required during checkout.
- (c) Propellant inlet conditions verified per Table XIV as correct continuously for previous three minutes.
- (d) Controller self test condition satisfactory.
- (e) Thrust Level and Mixture Ratio commands have been received.
- (f) There are no I responses as defined in Table XII in effect.

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The Engine Ready status shall be negated (Engine Status Word set to Purge Sequence No. 4) if system conditions cease to satisfy Engine Ready requirements any time prior to Start command.

Power Range Control Functional Element - This functional element contains the sequential and performance control logic necessary for operation of the Space Shuttle Main Engine during the Start, Mainstage, and Shutdown Phases of operation.

Start Sequencing - Start Sequencing shall be initiated upon receipt and validation of a Start command from GNC. Initiation of this sequence coincides with the beginning of the Start Phase of engine operation. Operations performed as part of the start sequence are defined in Table XV.

Shutdown Sequencing - Shutdown sequencing shall be initiated upon receipt and validation of a Shutdown command from the GNC or upon controller derived limit shutdown commands. Program logic shall provide for engine shutdown from any power level.

Normal Shutdown - A shutdown is normal if initiated by a Shutdown command from the GNC when engine thrust is between Minimum Power Level (MPL) and Emergency Power Level (EPL), the thrust and mixture ratio control loops are active, and no engine failure conditions exist which could interfere with the sequence. - The sequence for such a normal shutdown shall be as defined in Table XVI.

Limit Shutdown - Limit Shutdown of the engine shall be initiated when hydraulic actuation controls are functional for the propellant valves and an Engine Limit Exceeded indication via the Engine Status Word is received from the Limit Monitoring Functional Element as described in "Limit Shutdown Monitoring". Specific cases where Limit Shutdown conditions exist

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are indicated by the S responses in Table XII. During Start after ignition has been confirmed (see Table XV) and during Mainstage, the Limit Control Enable command must be in effect before Limit Shutdown is initiated. If the Limit Control Inhibit command is in effect for these phases, the Limit Shutdown Logic shall not cause an engine shutdown.

If the thrust reference is greater than MPL, then the Limit Shutdown sequence shall be initiated at the beginning of Part A of Table XVI.

If the thrust reference is less than or equal to MPL then the Limit Shutdown sequence shall be initiated at the beginning of Part B of Table XVI.

Emergency Pneumatic Shutdown - Emergency Pneumatic Shutdown' shall be initiated when any one of the following conditions is verified three successive times for each measurement channel.

(a) Failure of hydraulic actuation controls to any propellant valve as indicated by the failure of both actuator channels.

(b) Failure of two or more channels of a triple redundant sensor.

(c) Electrical power has been lost and then recovered after a 50 (plus 20, minus 0) millisecond period and all propellant valves have not reached closed at the time of power recovery.

Pneumatic Shutdown will also be the result of power loss to solenoid and torque motor coils when both channels of the controller or 400 Hz Power Bus fail. Specific cases where Pneumatic Shutdown conditions exist are indicated by PS responses in Table XII.

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Pneumatic Shutdown shall be initiated by de-energizing the fail-safe coils of all actuators and the Emergency Shutdown Control Valve Coil. The Engine Status Word shall be changed to indicate the Fail-Safe Pneumatic mode of the Shutdown phase and to indicate Component Failed.

When all propellant valves reach the closed position, the shutdown sequence then continues at the beginning of Part C of Table XVI.

When both Limit Shutdown and Pneumatic Shutdown conditions exist concurrently, Pneumatic Shutdown shall have precedence. The Limit Control Inhibit command shall not prevent Pneumatic Shutdown of the engine.

Performance Control Requirements - The Power Range Control Functional Element shall contain the control logic necessary for the Space Shuttle Main Engine system to satisfy the performance control criteria set forth in RC1007.

Temperature Limit Control - The High Pressure Oxidizer Turbopump (HPOT) and High Pressure Fuel Turbopump (HPFT) Turbine Discharge Temperatures shall be monitored for Temperature Limit Control in accordance with RC1007 and the requirements stated herewith. The Temperature Limit Control shall be enabled when (a) the engine is in the Start or Mainstage phase of operation, (b) the Limit Control Enable command has been received from the vehicle and is in effect and (c) ignition has been confirmed. The Engine Status Word shall be changed to indicate the Thrust Limiting mode when the Temperature Limit Control has been enabled and one of the following conditions exists:

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(a) Both measurements channels of a Temperature Limit control sensor indicate operation outside the limits and conditions specified in Table I.

(b) Thrust is otherwise being limited by the Temperature Limit Control.

If both measurement channels of a Temperature Limit Control sensor have passed reasonableness tests but failed the comparison tests, the lower indicated temperature shall be used for Temperature Limit Control. The Temperature Limit Control shall be deactivated upon initiation of the Shutdown phase, or when the Limit Control Inhibit command is in effect.

Chamber Coolant Valve Position Scheduling - The CCV position shall be scheduled as a function of engine thrust reference when the thrust reference is at or above the MPL level. Valve actuator position shall be scheduled linearly with thrust reference so as to be 30 percent open at MPL and full open at NPL. The CCV shall be full open at thrust reference levels above MPL.

Main Oxidizer Valve Position Scheduling - The MOV position shall be scheduled as a function of computed engine thrust after MPL has first been attained at engine start. Valve actuator position shall be scheduled linearly with thrust so as to be full open at NPL and (TBD) percent open at MPL. The MOV shall be full open at thrust levels above NPL.

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Main Fuel Valve Position Scheduling - The MFV position

shall be scheduled as a function of computed engine thrust after NPL has first been attained at engine start. Valve actuator position shall be scheduled linearly with thrust so as to be full open at NPL and 62 percent open at MPL. The MFV shall be full open at thrust levels above NPL.

Post-Shutdown Control Functional Element - This functional

element contains the logic for engine control during the Post Shutdown phase of engine operation. Executive, Controller Self-Test, Sensor Data Processing and GNC Data Processing Functional Element operations applicable to Post Shutdown shall be continuously active during this phase. Requirement for each of the three modes of operation are defined in the following subparagraphs. The Emergency Shutdown Control Valve shall remain de-energized during all modes of Post Shutdown except for the Abort Turnaround modes.

Standby - The Post Shutdown Functional Element shall

automatically begin operation in this mode. This mode of operation is the normal status for control operation at the completion of shutdown.

Propellant Dump - This mode of Post Shutdown operation

shall be initiated upon vehicle command if the preceding shutdown was not caused by a failure of the MFV or MOV actuator. The sequence is always initiated from the Standby Mode of the Post Shutdown Phase. Vehicle commands required for this mode of operation and the sequence in which they are normally received are: Oxidizer Dump, Fuel Dump, and Terminate Propellant Dump. This sequence may be modified by a Terminate Propellant Dump command used to terminate an oxidizer dump.

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Oxidizer is always dumped before fuel, only one main valve may be open at any time, and a fuel dump must always be preceded by a 10 second fuel system purge. The sequence and timing for this mode is defined in Table XVII. Part A of the sequence, oxidizer dumping, is initiated by receipt of an Oxidizer Dump command. Part B of the sequence, fuel dumping, is initiated by a Fuel Dump command which also terminated Part A of the sequence. Part C of the sequence, propellant dump termination, is initiated by a Terminate Propellant Dump command which shall terminate oxidizer dump or fuel dump at any point in the sequence.

Abort Turnaround - This mode of Post Shutdown operation shall control system purges and propellant conditioning during preparation for engine start after an abort. It shall be initiated upon vehicle command if the preceding shutdown was not caused by an engine malfunction. The sequence must always be initiated from the Standby Mode of the Post Shutdown Phase. Vehicle commands required for this mode of operation and the sequence in which they must be received are Abort Turnaround Sequence No. 1 and Abort Turnaround Sequence No. 2.

Abort Turnaround Sequence No. 1 (Initiation of Gaseous Nitrogen (GN₂), Fuel System, and Intermediate Seal Purges) - The operations associated with this sequence are initiated after validation of an Abort Turnaround Sequence No. 1 command from the GNC. The sequence continues until a new valid command is received from the vehicle. Operations of this sequence are defined in Table XVIII, Part A.

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Abort Turnaround Sequence No. 2 (Propellant Recirculation) -

Vehicle commands for initiation of this sequence shall not be accepted unless the operations of Sequence No. 1 have been accomplished and at least 2 minutes have elapsed since initiation of Sequence No. 1. After receipt and validation of an Abort Turnaround Sequence No. 2 Command from the vehicle, the operations of Table XVIII, Part B shall be performed.

Limit Monitoring Functional Element - This functional element shall check engine limit shutdown parameters and actuator position errors for their values relative to specified limits which are a function of the operating information shall be updated and either switching to continued operation on a redundant channel, or engine shutdown initiated in accordance with "Malfunction Response".

Actuator Position Error Monitoring - This function shall be performed during all phases of engine operation. The computer produced position reference signal for each actuator channel shall be compared with its corresponding actuator channel position indication to obtain an indicated position error. If excessive position error is confirmed with three successive samples, the controller shall respond in accordance with the corrective action specified for servovalve channel failure. If the servo positioned actuator has been commanded and reached full open or closed, then a position error greater than 2 percent on both channels shall cause switching.

Limit Shutdown Monitoring - Engine parameters shall be monitored to determine conditions for Limit Shutdown in accordance with RC1007 and the following subparagraphs. For conditions which cause Pneumatic Shutdown refer to "Emergency Pneumatic Shutdown".

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Start Transient Parameter Monitoring - The Main

Combustion Chamber Pressure shall be monitored during Start, after ignition has been confirmed, to verify that the pressure remains within the specified limits as a function of time. Three successive out of limit pressure indications shall cause Engine Limit Exceeded to be indicated by the Engine Status Word, the failure identification word to be set to 121 and Limit Shutdown initiated in accordance with "Limit Shutdown".

Limit Shutdown Parameter Monitoring - Engine limit

Exceeded shall be indicated by the Engine Status Word and Limit Shutdown initiated in accordance with "Limit Shutdown" if either of the following conditions have been verified three successive times for each measurement channel.

(a) When all measurement channels, which have passed sensor reasonableness tests, for an engine limit parameter indicate operation outside the engine limits and conditions imposed by Table II, the failure identification word shall be set to indicate one of the "out of limits" failure modes.

(b) When both measurement channels of a dual redundant sensor used for Engine Limit Shutdown Control fail to pass reasonableness tests, the failure identification word shall be set to indicate that one of the sensor channels has failed.

Sensor Data Processing Functional Element - This functional

element contains the logic for sensor data scaling, tests, and performance parameter calculations.

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Types of Sensor Data Processing - Sensor data processing shall depend upon the application of the measured data.

Data Scaling - Raw data from all sensors shall be scaled to accommodate sensor calibration curve characteristics and obtain measured parameter values for use in controller calculations and maintenance recording. The coefficients of these equations shall be data constants in the program which can be changed when sensors are replaced in the engine system. Raw data from non-redundant sensors shall not be scaled.

Sensor Data Reasonableness Tests - After data scaling, reasonableness tests shall be performed on data from specified sensors. Data from sensors failing this test shall not be used in controller performance calculations. If a measurement fails the reasonableness test three successive times it shall be continuously rejected until a Controller Reset command is received and implemented.

Comparison Tests - Comparison tests shall be performed on specified dual and triple redundant measurements. If one measurement channel of a triple redundant sensor fails the comparison tests three successive times, that channel shall be continuously rejected until a Controller Reset command is received and implemented.

GNC Data Processing Functional Element - This functional element shall process engine status, performance and maintenance trend data to the proper format required for transmission to the GNC/Engine Interface. Data and command word format are defined in Table VII.

Data Base - Parameter measurements, sensor ranges, units of measure which shall be accommodated by the Controller Program are defined in RC1007 and Tables IX, I, and VI.

3.3.2.2 Reaction Control Subsystem

The Reaction Control Subsystem can be simulated by dividing the system into four basic areas of equations. Figure 3.3.2.2 shows the four equation groups and the general interface requirements. Because of the fast response rate of the real world system, the simulation is approached for thrust from the equivalent engineering parameter of total impulse. The helium pressurization equations are to be a combination of exact engineering relationships and functional representation.

The helium pressurization equations will use the EPS power available booleans and the crew station switch and circuit breaker state to derive the valve state. Primary helium storage tank pressure and mass is calculated from helium usage. Helium usage is based on RCS fuel remaining in the tank. Helium pressure on the bladder hydrazine tank is calculated as dependent on the helium regulation supply.

The hydrazine fuel equations provide the calculations for the fuel remaining in the tank. Fuel usage will be calculated by the thrust equations. A fuel available and pressurized boolean will be generated for the thrust equations.

The thrust and force equations will calculate the total impulse of the RCS jets as they fire. An interface program with the G, N and C computer will provide the thrust equations with booleans for firing the jets and a length of time fired parameter. These conditions, along with electrical power for the catalytic heater through switches and circuit breakers, will be used to computer the total impulse of each jet since the last computer cycle through this program. The electrical load for the catalytic heater will be calculated for the EPS program and the total impulse will be generated for the EOM program. The computed impulse will take into account the loss of efficiency as the result of atmospheric pressure.

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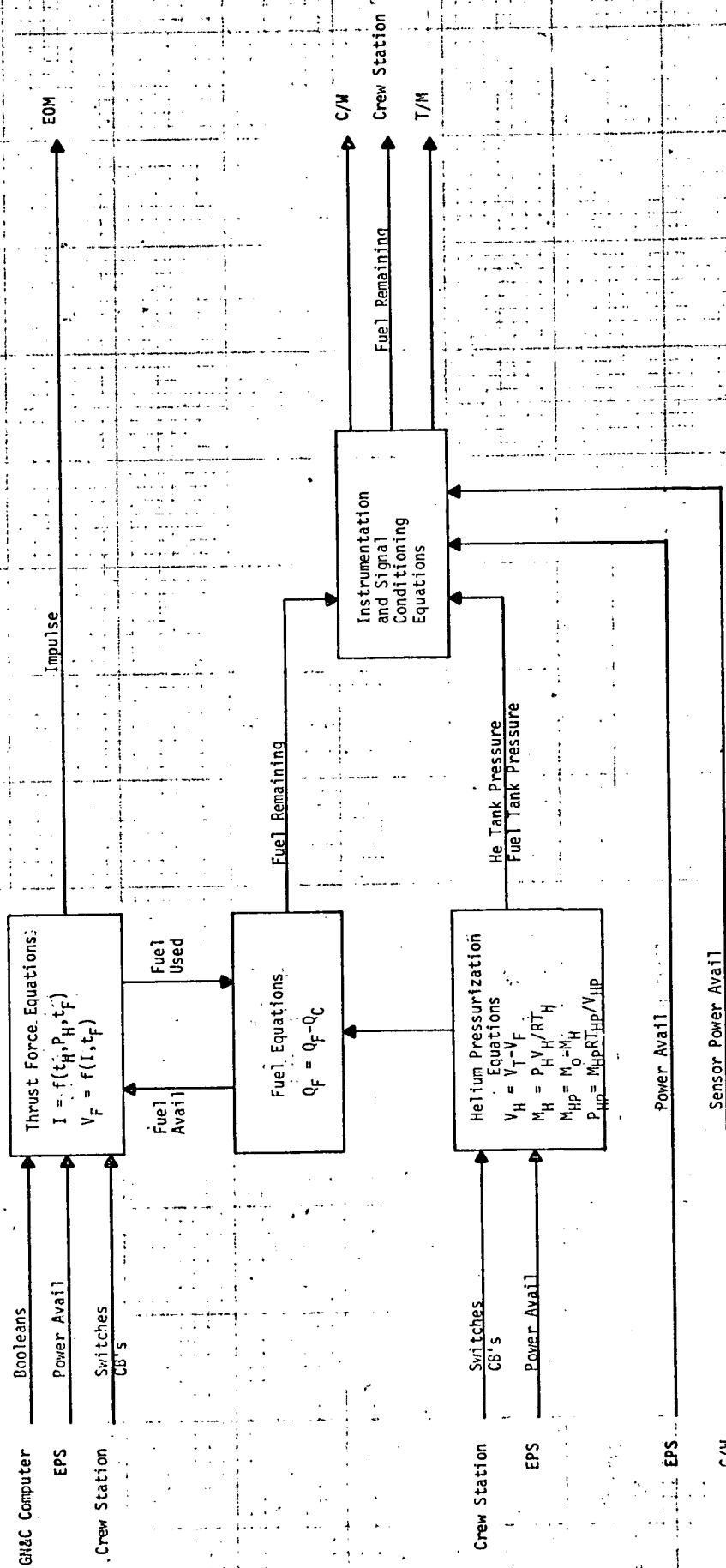
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The instrumentation and signal conditioning equations will accept parameters simulating the actual system state and condition these parameters using sensor and display logic booleans from the Electrical Power Subsystem for crew station display, for input to the Caution and Warning Subsystem, or for input to the Telemetry Subsystem Multiplexer Program. The equations will be repeated for each reaction control system unit, either by programmed loops or by repetitive equations, whichever requires the least amount of computer time and core. Required malfunctions for the RCS simulation are to be designed into the simulation for minimum computer impact.

3.3.2.2 Reaction Control Subsystem



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where: V_H = Volume of Helium
 V_T = Volume of fuel tank
 V_F = Volume of fuel
 M_H = Mass of helium
 P_H = Pressure of helium
 T_H = Temperature of helium
 R = Universal gas constant
 M_{HP} = Mass of helium in high pressure tank
 M_O = Original mass of helium in high pressure tank
 P_{HP} = Pressure of helium in high pressure tank
 T_{HP} = Temperature of helium in high pressure tank
 V_{HP} = Volume of helium in high pressure tank
 Q_F = Quantity of fuel
 Q_C = Quantity of fuel consumed
 I = Impulse force of engine
 t_F = Firing duration per iteration
 t_H = Temperature of reaction plate

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3.3.2.3 Orbital Maneuvering Subsystem

The simulation of the Orbital Maneuvering Subsystem may be approached by a combination of logical equations, functional representative equations, and explicit engineering equations. Crew displays are provided for fuel, oxidizer, helium, and engine chamber pressure, and for oxidizer and fuel quantity.

Refer to Figure 3.3.2.3.

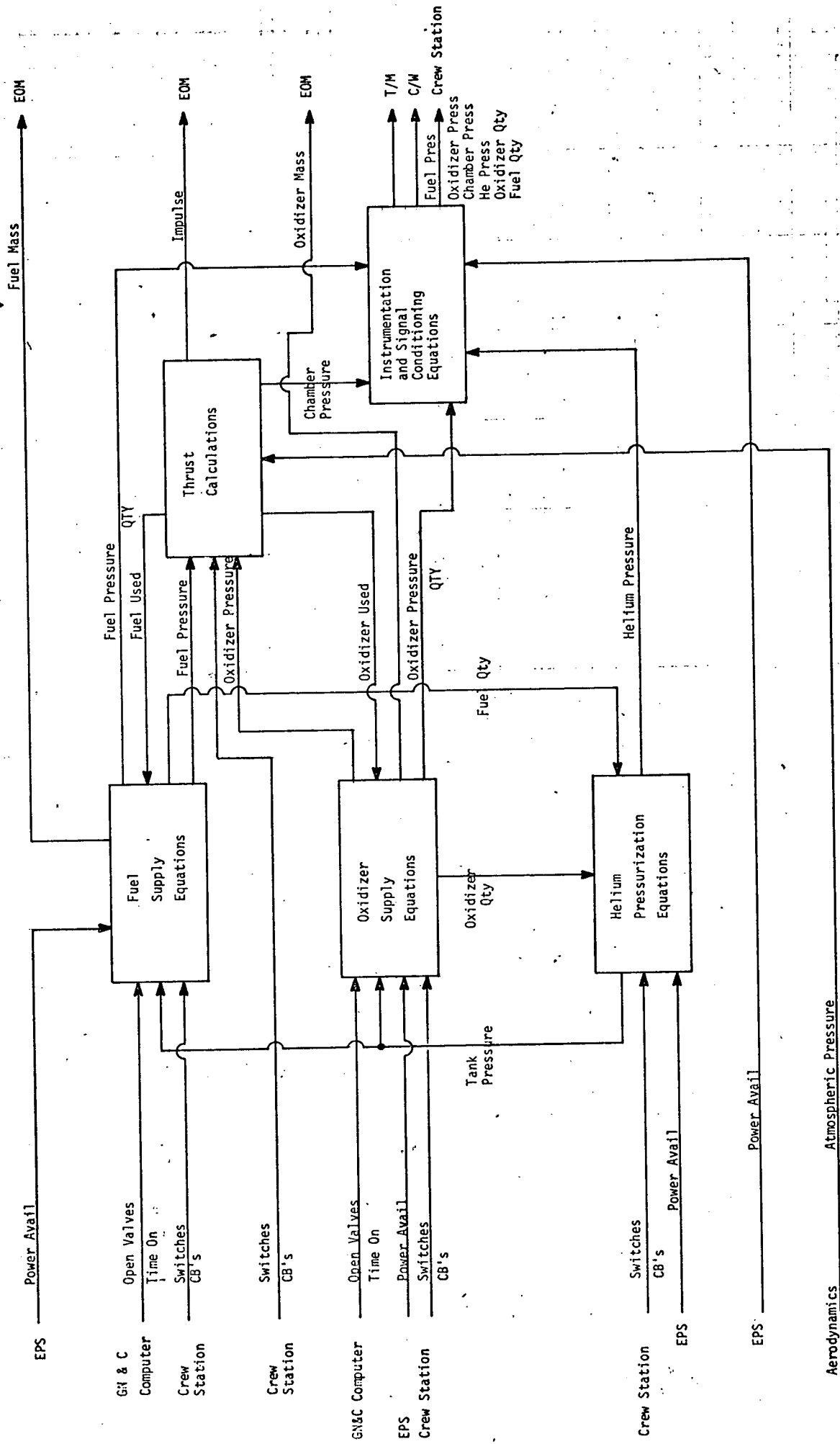
The helium pressurization equations will use the EPS power available booleans and the crew station switch and circuit breaker state to derive the valve state of the helium system. Primary helium storage tank pressure and mass is calculated from helium usage. Helium usage is based on the amount of propellants left in the oxidizer and fuel tanks. Helium pressure on the fuel and oxidizer is calculated as dependent on the helium regulation supply.

The fuel supply equations provide the calculations for the fuel quantity remaining in the tank. Fuel usage will be calculated by the thrust equations. A fuel available and pressurized boolean will be generated for the thrust equations.

The oxidizer supply equations perform the same basic function as the fuel equations - calculation of oxidizer quantity, oxidizer available and pressurized. Oxidizer usage will be calculated by the thrust equations.

The thrust calculations are to compute the impulse of the engines during the time period from the last iteration to the present iteration. This particular method will allow simulation of the correct impulse during both start-up and engine shut-down transients. The impulse from the engine will reflect the fuel and oxidizer pressure and the mixture ratio corrected by atmospheric pressure.

Figure 3.3.2.3 - Orbital Maneuvering System



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Chamber pressure will be calculated for display purposes from the computed impulse force.

The instrumentation and signal conditioning equations will accept parameters simulating the actual system state and condition these parameters using sensor and display logic booleans from the Electrical Power Subsystem for crew station display, for input to the Caution and Warning Subsystem, or for input to the Telemetry Subsystem Multiplexer Program. The equations will be repeated for each Orbital Maneuvering system unit, either by programmed loops or by repetitive equations, whichever requires the least amount of computer time and core. Required malfunctions for the OMS simulation are to be designed into the simulation for minimum computer impact.

3.3.2.4 Air Breathing Engine System

The Air Breathing Engines of the shuttle vehicle are to be simulated using a closed-loop dynamic functional math model. The fundamental overview of the engine shows fuel management, crew displays, throttle control, and thrust as the primary system functions.

The throttle is the primary input to the fuel control system. In addition the fuel flow responds to the high pressure compressor rotor speed and discharge pressure, the low pressure compressor inlet air temperature and pressure, and the internal burner pressure.

The engine inlet air temperature is a function of the ambient air temperature and the ram air effects from aircraft speed. The inlet pressure is also dependent on ambient air pressures and the ram air effects.

The airflow of the compressors is a function of the inlet conditions as well as the rotor speed and ducting losses.

The burner outlet pressure and temperature are functions of the high pressure compressor outlet pressure, fuel flow, airflow through the compressor, and air bleed losses. The turbine rotor speed is a function of burner outlet pressure, engine intake pressure, and power losses internal to the engine.

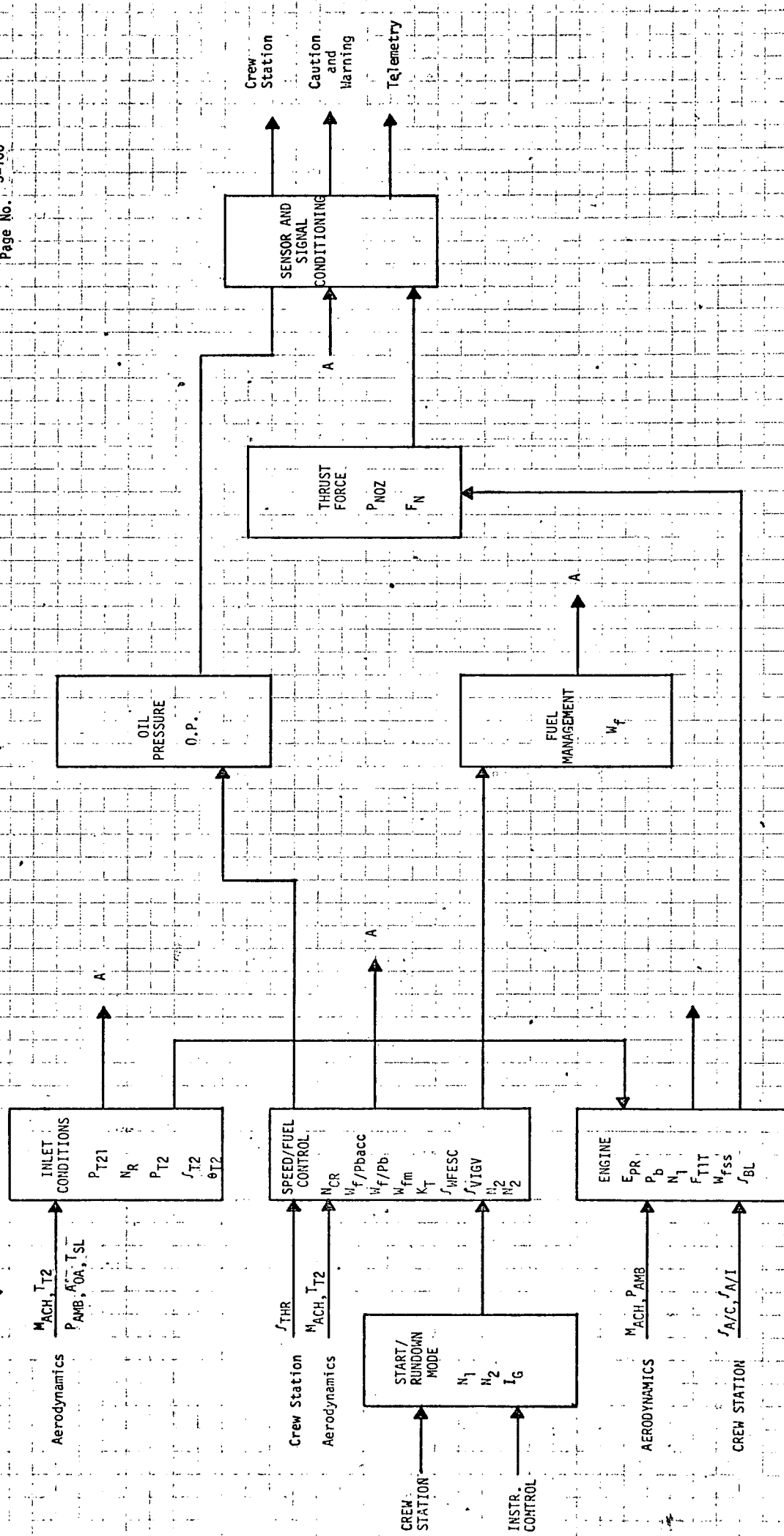
The thrust force is the reaction to eject the exhaust gas. The exit velocity is dependent on the burner outlet conditions, rate of mass flow through the burner, and the turbine rotor speed.

A generalized diagram of the functional relationships of the engine system is shown in Figure 3.3.2.4.

Ground start, ram air start, and rundown are to be simulated using performance data from tests. Malfunctions (or instructor control features) will be provided to simulate hot start and slow start.

FIGURE 3.3.2.4
AIR BREATHING ENGINE SYSTEM

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Instrumentation and signal conditioning will be accomplished to the simulated parameters prior to display to the crew members. The parameters will be conditioned using sensor and display booleans from the Electrical Power Subsystem for crew station display, input to the Caution and Warning Subsystem, and input to the Telemetry Subsystem Multiplexer System.

The equations of the Air Breathing Engine Subsystem will be repeated for each engine, tank, and throttle system either by programmed loops or by repetitive equations. Required malfunctions of the system will be designed into the simulation model for minimum computer impact.

The inlet atmospheric conditions and ram air effects are to be simulated by the following general equations:

- 1) Ideal ram pressure:

$$P_{T2} = f(P_{AMB}, M_{ACH})$$

$$N_R = f(M_{ach}, AOA)$$

- 2) Compressor face pressure

$$P_{T2} = f(N_R, P_{T21})$$

- 3) Pressure correction factor

$$\delta T_2 = K \cdot P_{T2}$$

- 4) Temperature correction factor

$$\theta_{T2} = T_{T2}/T_{SL}$$

The speed/fuel control effects are given by:

- 5) Control reference speed

$$N_{CR} = f(\delta_{THR}, P_{T2}, T_{T2}, Mach)$$

- 6) Acceleration Schedule

$$W_{f/P_{bACC}} = f(N_2, T_{T2}, \delta_{THR})$$

7) Fuel Metering

$$W_f/P_b = K_{GD} (N_{CR} - N_2)$$

8) Metered fuel flow

$$W_{fm} = (W_f/P_b * P_{BX} * \delta_{WFESC})$$

or

$$W_{fm} = (W_f/P_b * P_{BX} * \delta_{FESC})$$

9) Engine function

$$K_T = f[N_2, P_b, T_{T2}, (W_{fm} - W_{fss})]$$

10) Electronic Control

$$\delta_{wfesc} = f(FT1T - FT1T)$$

$$\delta_{V1GV} = FAN - f(N_1)$$

11) Rotor Acceleration

$$\dot{N}_2 = f[(W_{fm} - W_{fss}), K_T]$$

12) Rotor Speed

$$N_2 = \int \dot{N}_2 dt$$

The oil pressure of the engine is a function of the rotor speed and temperature.

13) Oil Pressure

$$O.P. = f(N_2, T_{T2})$$

The fuel management will be calculated from fuel usage.

14) Fuel Quantity

$$W_f = W_f - W_{fm}$$

The engine parameters are calculated by the following general equations:

15) Engine pressure ratio

$$EPR = f(N_2, MACH, \delta_{BL}, \delta_{V1GV})$$

16) Engine Burner Pressure

$$P_b = f(EPR, Mach, \delta_{BL}, \delta_{T2})$$

- 17) Low Pressure Rotor Speed

$$N_1 = f(EPR, MACH, \delta_{BL}, \sqrt{\theta_{T2}})$$

- 18) Fan Turbine inlet temperature

$$FTIT = f(EPR, MACH, \delta_{BL})$$

- 19) Steady State fuel flow

$$W_{fss} = f(EPR, MACH, \delta_{BL}, \delta_{T2}, \sqrt{\theta_{T2}})$$

- 20) Bleed Air

$$\delta_{BL} = f(\delta_{A/C}, \delta_{A/I})$$

The thrust force is then calculated by:

- 21) Nozzle Pressure

$$P_{NOZ} = f(EPR, MACH, \delta_{BL}, P_{AMB})$$

- 22) Net Propulsive Thrust

$$F_N = f(P_{NOZ}, W_{FM})$$

Following these looped equations for the four engines, the parameters would then be conditioned for transfer to displays or other software programs such as Caution and Warning or Telemetry.

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AOA	Aircraft angle of attack
EPR	Engine pressure ratio
FN	Engine thrust
FTIT	Fan turbine inlet temperature
K_{BCB}	Burner cutback constant
K_{τ}	Engine time constant coefficient
MACH	Mach number
N_{CR}	Control reference speed
\dot{N}_2	High-pressure rotor acceleration
N_2	High-pressure rotor speed
O.P.	Engine oil pressure
P_{AMB}	Ambient pressure
P_b	Engine burner pressure
P_{bx}	Control reference burner pressure
P_{NOZ}	Convergent nozzle total pressure
P_{T2}	Compressor face total pressure
P_{T2I}	Ideal compressor face total pressure
T_{SL}	Sea level ambient temperature
T_{T2}	Compressor face total temperature
W_{fm}	Gas generator metered fuel flow
W_{fss}	Gas generator steady state fuel flow
W_{ft}	Total fuel flow
W_f/P_b	Fuel flow metering parameter
$\delta VIGV$	Variable compressor geometry effect

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$\delta_{A/C}$ Air-conditioning and utility bleed load

$\delta_{A/I}$ Anti-ice bleed load

δ_{BL} Total bleed load increment

δ_{THR} Throttle angle

δ_{T2} Total compressor inlet pressure ratio

θ_{T2} Total compressor inlet temperature ratio

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3.3.2.5 Solid Rocket Motor Subsystem

The Solid Rocket Motor System could be simulated by developing engineering relationships between thrust, chamber pressure, mass flow rates, etc.; however, the program must be run at a high iteration rate. Using engineering relationship equations would cause excessive computational time requirements. In addition, the approach would not yield as accurate results as use of non-real time simulated performance data. The crew has few switches, circuit breakers, and displays relating to the engine performance which also adds to the acceptability of use of the performance data tables.

The data that must be matched most closely is the reference trajectory data. The method requiring the least amount of computer time with a high accuracy is a table look-up and interpolation between points of the table for intermediate time values.

The suggested table will be composed of thrust, mass, mass position, and moment of inertia data stored at fixed time intervals. The time related parameters will be based on time from SRM ignition.

The thrust and mass interpolation equations block shown in Figure 3.3.2.5 will perform the table look-up of interpolation constants approximately once every second. In between table values, the program equations will compute interim parameter values. The computer parameters will be modified for off-nominal performance of the two SRM engines using instructor entered modifiers. These modifiers will allow the simulation to depict grain checking, sloughing, and contamination resulting in slow burning of propellants. The equations will generate parameters to stimulate audio cue devices for the engine sound/vibration. Thrust termination will generate audio cues for explosive devices and visual cues for the thrust termination ports. Thrust and mass parameters will be simulated

by curve fit equation. The equation will be modified by time since rocket ignition.

The calculation of thrust, mass, moment of inertia, and c.g. location will be accomplished by table lookup as a function of a modifiable time base, τ . The instructor will be able to increase or decrease the burn time of the engine by modifying the τ base.

$$\tau = f(t, I_c)$$

$$\text{and } T_F = f(\tau)$$

$$M = f(\tau)$$

$$I = f(\tau)$$

$$X = f(\tau)$$

$$Y = f(\tau)$$

where τ = relative time position of table data

t = time since ignition

I_c = instructor modifier

T_F = Thrust Force

M = Mass of rocket engine

I = Moment of inertia of rocket engine

X = X body position of c.g.

Y = Y body position of c.g.

The simulation of the sequential logic and mechanical functions for separation will be accomplished by logic equations. These equations will take into account explosive device armament by the crew and separation cues either by switch command or On-Board Computer inputs.

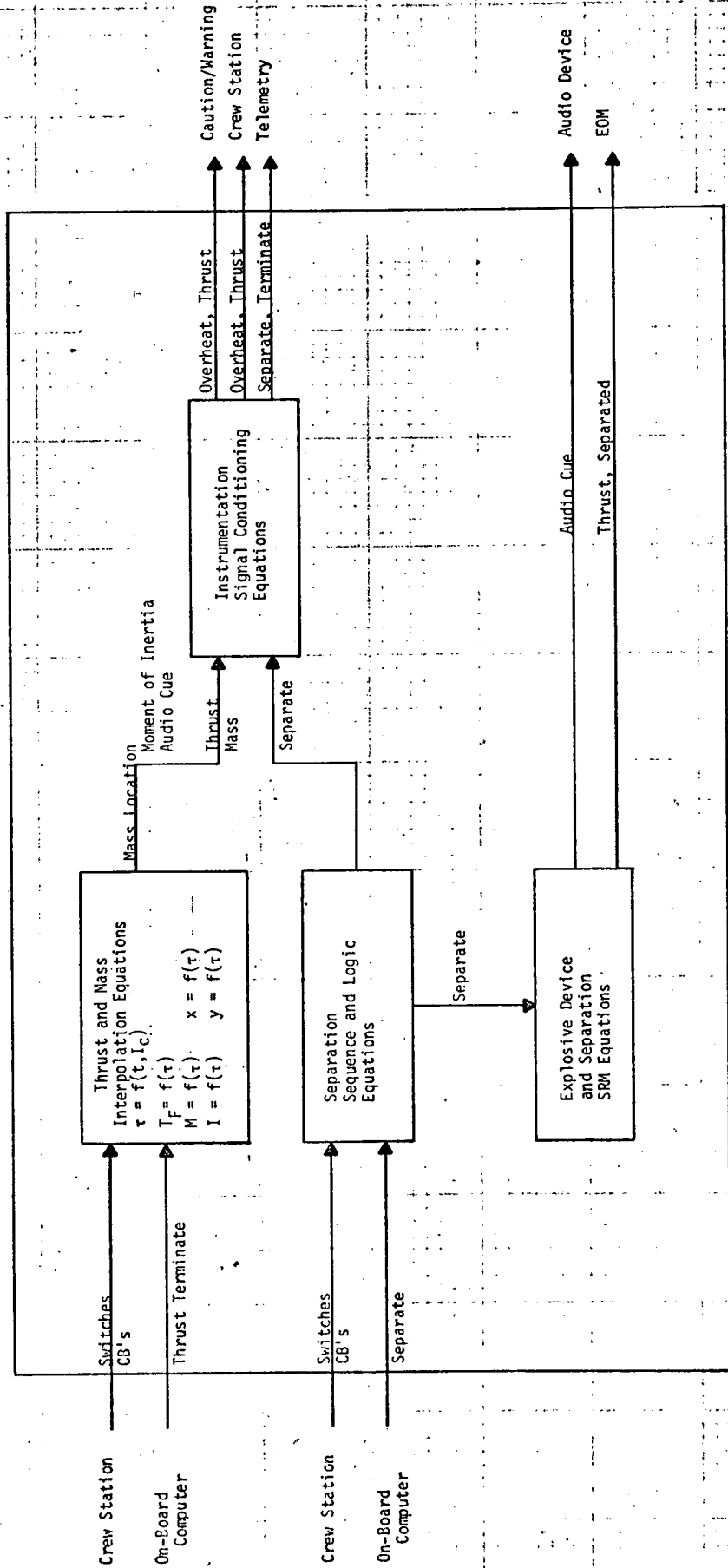
The explosive device equations will provide an audio cue, a cue to EOM indicating physical separation, and a cue to the separation SRM engines to ignite.

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The separation SRM equations will provide the thrust forces of the small rockets to the EOM program for the new "target" vehicles. Once the separation SRM has burned out, this program is no longer computed.

The instrumentation and signal conditioning equations accept parameters simulating the actual system state and condition these parameters using sensor and display logic booleans from the Electrical Power Subsystem for crew station display, for input to the Caution and Warning Subsystem, or for input to the Telemetry Subsystem Multiplexer Program. The equations will be repeated for each Solid Rocket Motor unit, either by programmed loops or by repetitive equations, whichever requires the least amount of computer time and core. Required malfunctions for the SRM simulation are to be designed into the simulation for minimum computer impact.

3.3.2.5. Solid Rocket Motor Subsystem



3.3.3 Vehicle Configuration System

3.3.3.1 External Tank Subsystem

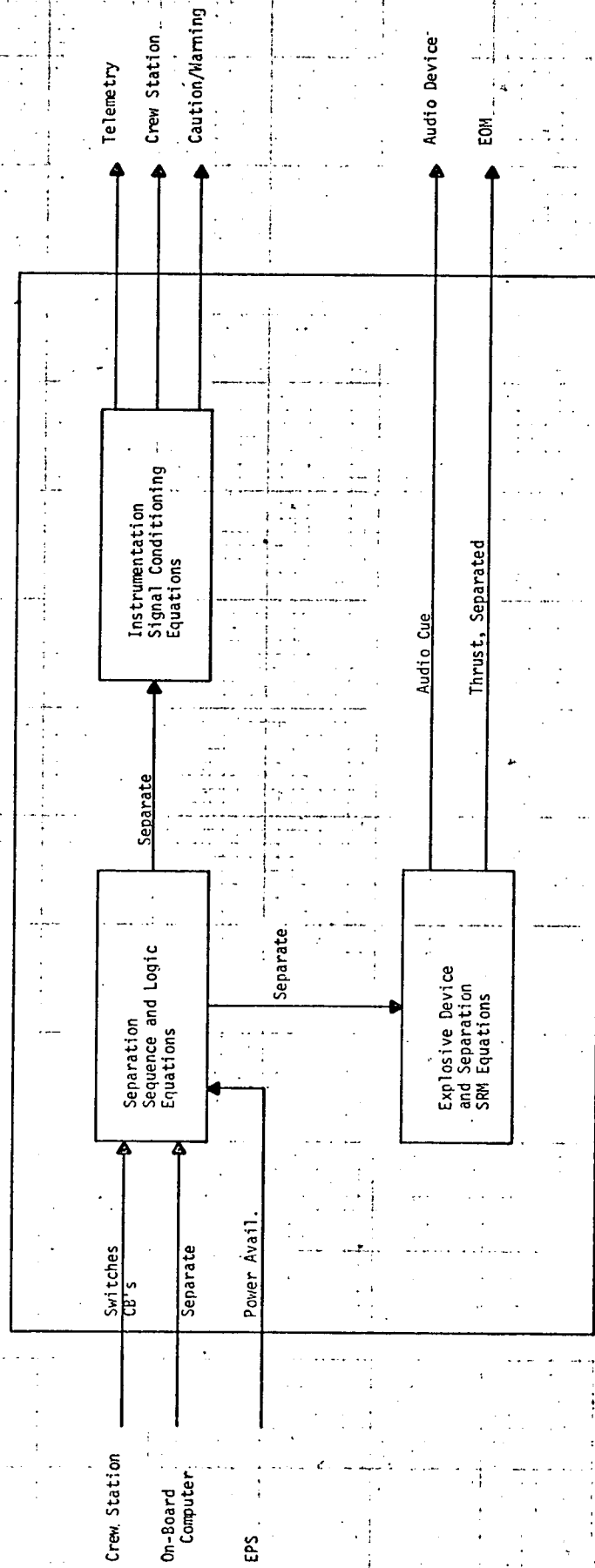
The simulation of the sequential logic and mechanical functions for External Tank System separation will be accomplished by logic equations.

These equations will take into account explosive device armament by the crew and separation cues either by switch command or On-Board Computer inputs.

The explosive device equations will provide an audio cue, a cue to EOM indicating physical separation, and a cue to the retro SRM engines to ignite. The retro rocket ignition cue will be based on the simulated external tank avionics state and separation attitude and distance data calculated from EOM attitude and position data. The separation SRM equations will provide the thrust force of the small rocket to the EOM program for the new "target" vehicle. Once the separation SRM has burned out, this program is no longer computed.

The instrumentation and signal conditioning equations accept parameters simulating the actual system state and condition these parameters using sensor and display logic booleans from the Electrical Power Subsystem for crew station display, for input to the Caution and Warning Subsystem, or for input to the Telemetry Subsystem Multiplexer Program. Required malfunctions for the simulation are to be designed into the simulation for minimum computer impact.

3.3.3.1 External Tank Subsystem



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3.3.3.2 Landing Gear Subsystem

The simulation of the Landing Gear Subsystem can be primarily considered best suited for logical equation solutions. Logical sequential functions will be simulated as time dependent parameters. The system may be divided into the four related groups of equations as shown in Figure 3.3.3.2.

The equations for gear deployment and retraction consider electrical power through switches and circuit breakers to the hydraulic servo valves used to unlock/lock, open/close wheel well doors, and raise/lower the landing gear. Time sequential delays will be incorporated into the equations to simulate the hydraulic power factor. A low hydraulic power factor will cause an increase in the time required for the hydraulic activator to move to the end position. A load parameter will be generated for the Hydraulic Power Subsystem. Gear-up and Gear-down parameters will be generated for use by other landing gear equations, and for display in the crew station. Drag force cues for gear and doors will be calculated for use by the Aerodynamic Forces Subsystem.

The equations of the landing force equations will take into account the EOM data for groundspeed rate of descent, position above the runway surface, and vehicle attitude to calculate the forces at each gear for the EOM program. Audio cues will be generated for touchdown of each gear. The oleo pressure and shock absorber deflection of each gear will be taken into account during landing and rollout so that the resultant position of the vehicle above the runway is realistic.

Steering forces for deflection of the vehicle from nose wheel attitude will be calculated for input to the EOM program. The position

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of the nose wheel will be calculated based on inputs from the crew station and the hydraulic power factor time response. Cues will be generated for audio indication of nose wheel steering movement including nose wheel shimmy.

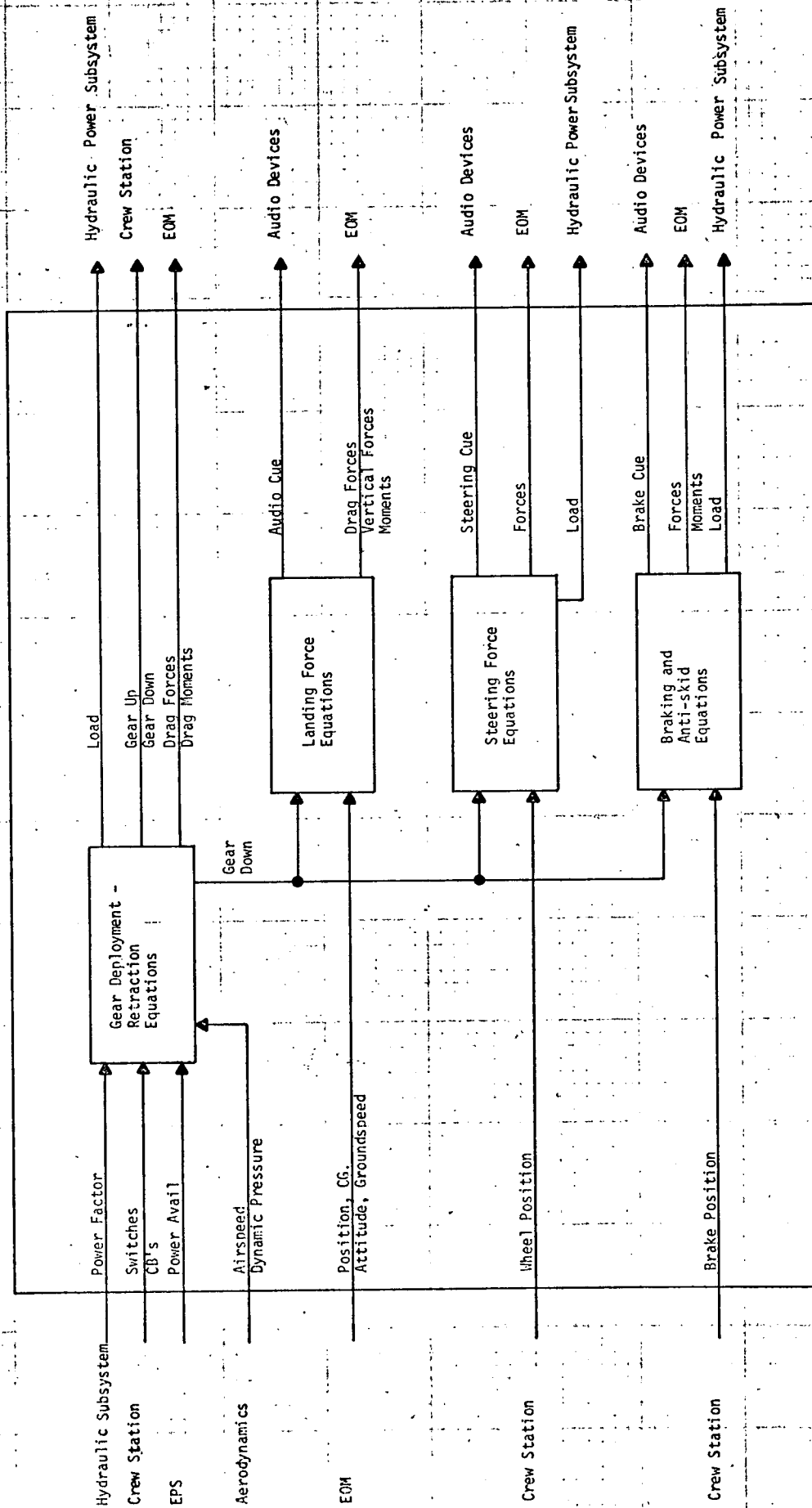
Hydraulic fluid usage load will be generated for the Hydraulic Power System.

The Braking and Anti-Skid equations will generate the horizontal braking force applied to each gear wheel set. Anti-skid system braking forces will be generated using simulated wheel rpm and the ground speed of the vehicle. Cues will be generated for the audio devices indicating braking of the carbon-on-carbon surfaces.

Off-nominal landing effects from water, ice, defective systems, etc., will all be instructor controlled inputs as malfunctions.

From these groups of equations, parameters simulating the actual system state will be conditioned using sensor and display logic booleans from the Electrical Power Subsystem for crew station display, for input to the Caution and Warning Subsystem, or for input to the Telemetry Subsystem Multiplexer Program, if applicable. The equations will be repeated for each landing gear unit, either by programmed loops or by repetitive equations, whichever requires the least amount of computer time and core. Required malfunctions for the landing gear are to be designed into the simulation for minimum computer impact.

3.3.3.2 Landing Gear System



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3.3.3.3 Drag Chute Subsystem

The drag chute will require a minimum logical simulation approach. Chute deployment logic will be computed from electrical power available, circuit breaker, and switch state. Following deployment, the chute drag force will be generated based on vehicle airspeed and the distance of the chute centerline above the ground. The logic of chute release will be nearly identical to the chute deployment equation. Parameters used for display or as inputs to the Caution and Warning or Telemetry programs will be signal conditioned with sensor power booleans from the Electrical Power Sub-System. The malfunctions for the drag chute simulation are to be designed into the simulation for minimum computer impact.

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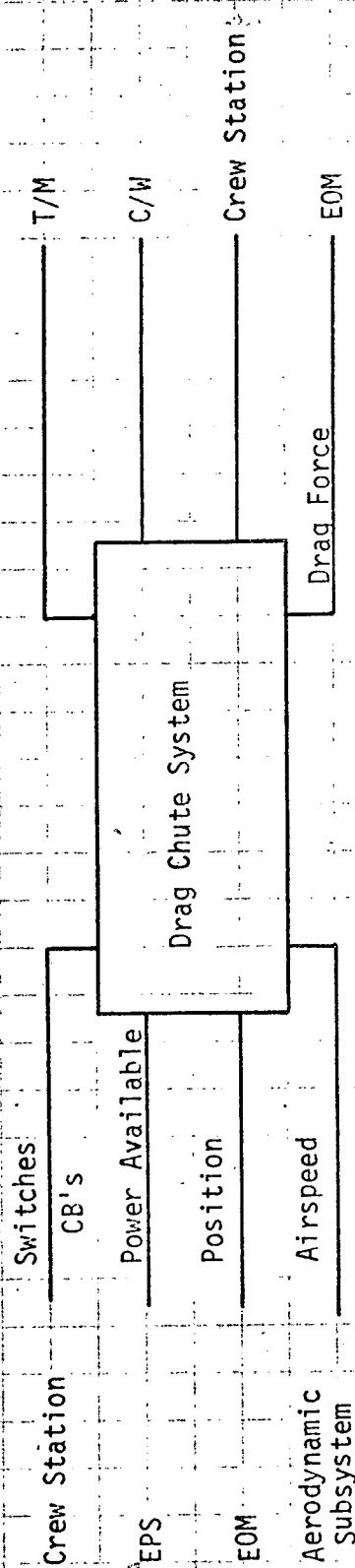


Figure 3.3.3.3

DRAG CHUTE SUB-SYSTEM

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3.3.3.4 Docking Subsystem

The simulated docking subsystem will simulate the operation of the shuttle docking mechanism. Inputs to the system will include the shuttle-to-target vehicle position vector (target vehicle translational EØM), shuttle-to-target-vehicle direction cosines (target vehicle rotational EØM), shuttle vehicle direction cosines (shuttle rotational EØM), and instructor inputs (malfunctions, etc.). Outputs will include forces and moments upon both the shuttle vehicle and target vehicle exerted by the docking mechanism. The docking mechanism is assumed to be deployable, and to be operative only when deployed. The device will be simulated accordingly. If deployment requires a noticeable finite time, and if this effect is visible to the crew, the simulated mechanism will also exhibit a similar finite deployment time. State information for the two vehicles will be used to calculate the relative positions and attitudes of the two docking devices. The particular configuration of the docking device present on a given mission will be simulated. Depending on present relative state (and docking mechanism configuration), forces and moments upon both vehicles due to the operation of the guide cone, actuators/attenuators, or alignment rings are calculated. When relative position and attitude (and malfunction status) is proper, capture latches will be simulated to be closed, and resulting forces and moments will be calculated. Hard dock will be simulated to occur when the proper relative state exists (and malfunctions have not rendered it impossible). Upon hard dock, a boolean will be set to cause target vehicle mass properties to be included with shuttle mass properties. Unlatching of a docked vehicle will be simulated as occurring upon remote command, providing relevant switches and breakers are properly configured, power is available, and the system has not been malfunctioned in such a way as to prevent release. Upon release, target vehicle EØM will be

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reinitialized from shuttle EOM. The fail-safe docking device jettison ordnance will be simulated for emergency use. An update interval of 100 milliseconds is used for the docking subsystem simulation, which matches the update rate for target vehicle EOM. The conceptual design for the simulation of the docking subsystem is sketched in Figure 3.3.3.4.-1.

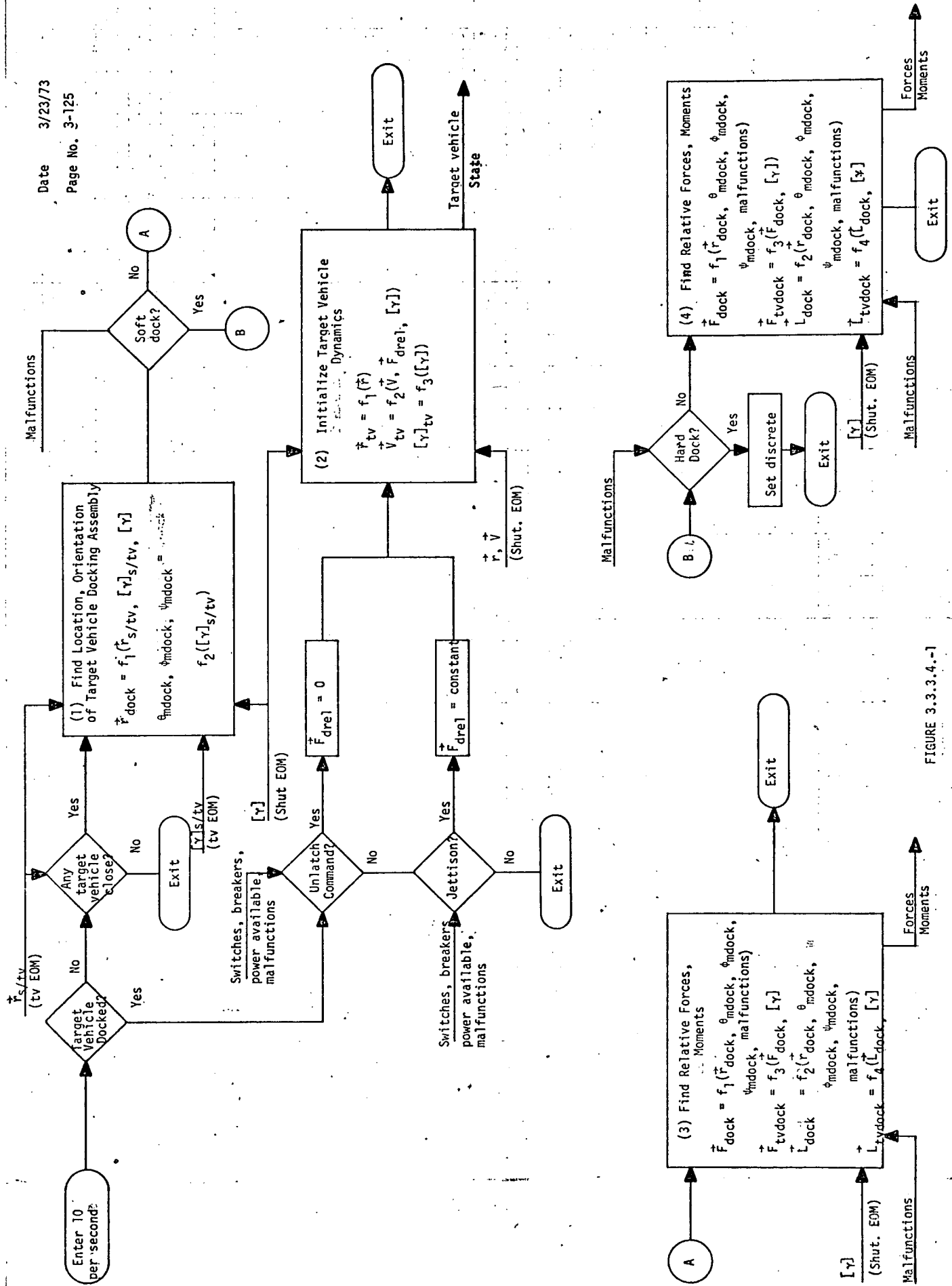


FIGURE 3.3.3.4.-1

Symbol Dictionary for Figure 3.3.3.4.-1

\vec{F}_{dock}	force exerted by docking mechanism on shuttle	$[\gamma]$	shuttle attitude direction cosines
\vec{F}_{drel}	unlatching/jettisoning impulse	$[\gamma]_{s/TV}$	shuttle body to target vehicle body direction cosines
\vec{F}_{TVdock}	force exerted by docking mechanism on target vehicle	$[\gamma]_{TV}$	target vehicle attitude direction cosines
\vec{L}_{dock}	torque exerted by docking mechanism on shuttle	θ_{mdock}	pitch docking misalignment
\vec{L}_{TVdock}	torque exerted by docking mechanism on target vehicle	ϕ_{mdock}	roll docking misalignment
\vec{r}	shuttle inertial position	ψ_{mdock}	yaw docking misalignment
\vec{r}_{dock}	relative position of target vehicle docking assembly (shuttle body-fixed coordinates)		
$\vec{r}_{s/TV}$	shuttle-to-target vehicle vector (inertial coordinates)		
\vec{r}_{TV}	target vehicle inertial position		
\vec{V}	shuttle inertial velocity		
\vec{V}_{TV}	target vehicle inertial velocity		

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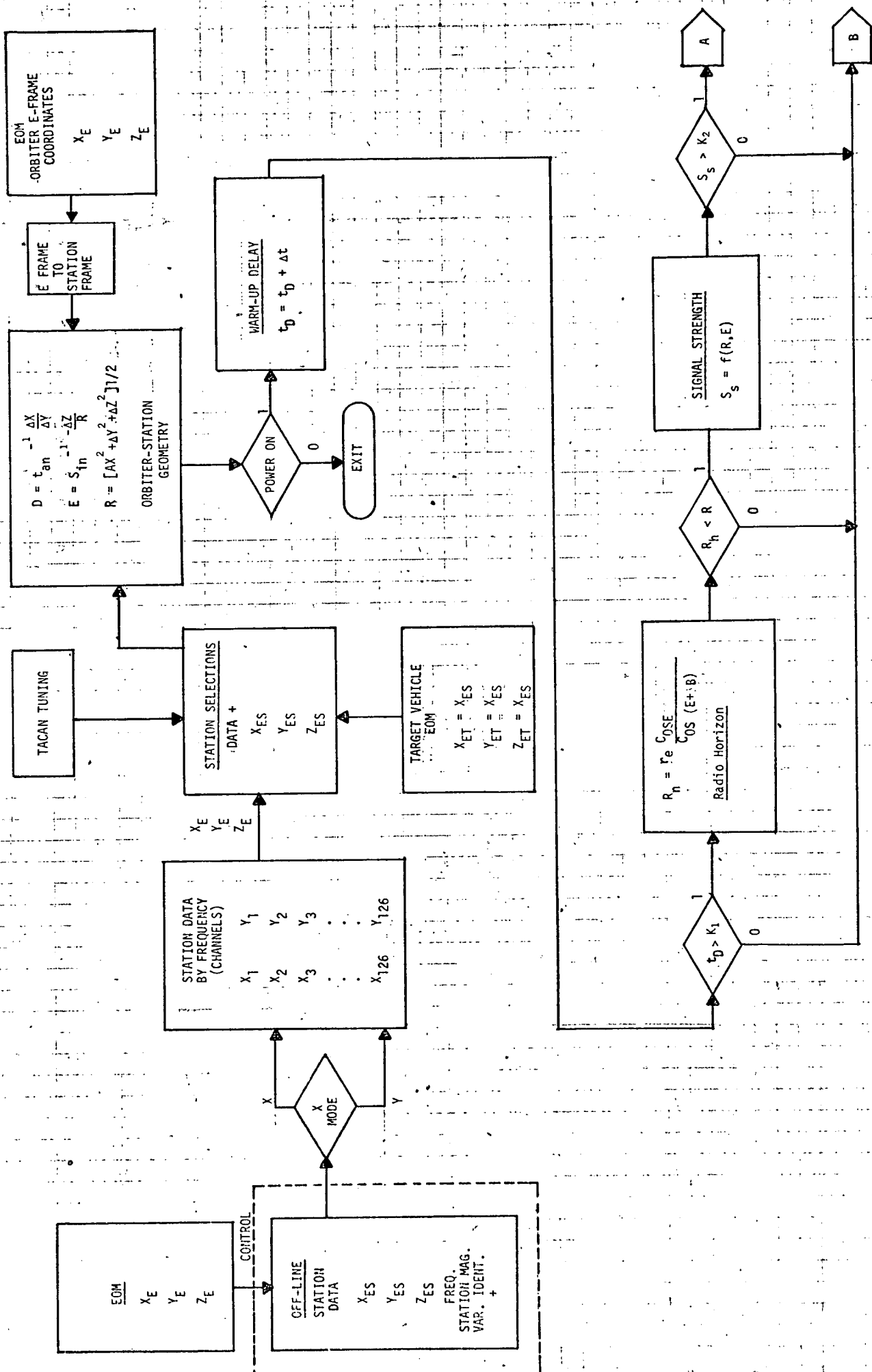
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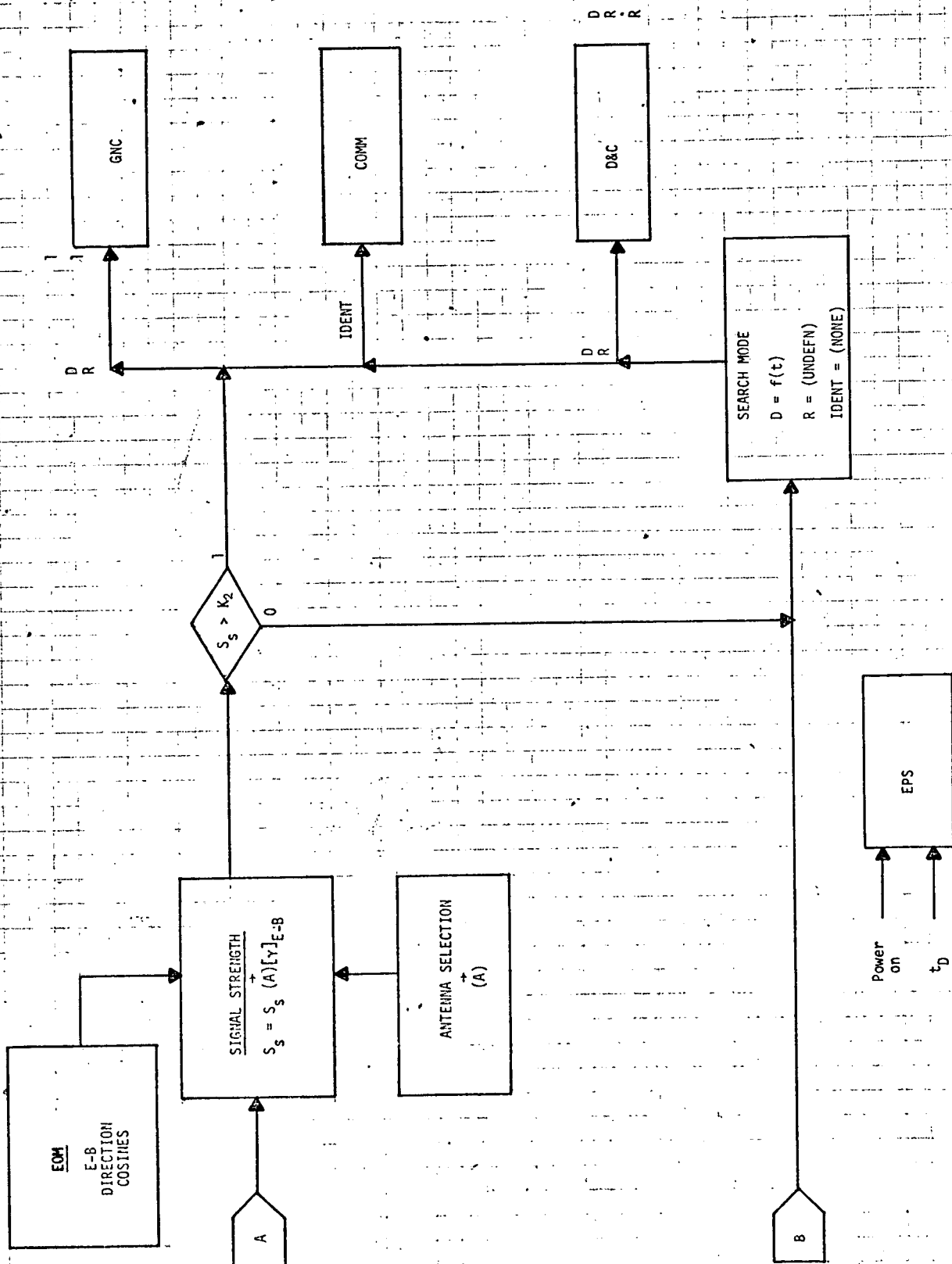
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3.3.4 Communications/Tracking System3.3.4.1 TACAN Subsystem

The Space Shuttle Subsystem contains the three TACAN Transmitter/Receivers, control panels and L band antennas located in the orbiter and makes use of existing ground TACAN facilities. The orbiter controls are located on the pilot center console and include the three 3-digit frequency selectors, the three X-Y mode switches, the three test switches and three local/master switches. The NAV AUDIO switch contains positions for monitoring the TACAN station identification signals. The TACAN Master Switch selector (3 position) and local/master switches allow advance set-up of the panel to sequentially select three stations or to obtain simultaneous information from up to three stations if in range. The X-Y mode control provides for operation on any one of 252 paired frequency channels, 126 for each position of the switch. Station identification is provided by receipt of the transmitted 1350 hz station identification call letters. The TACAN operates by flight interrogation pulsing of the ground based beacon system. There is a search mode in which the system is pulsed at a relatively high frequency. Once lock-on is achieved, the system provides bearing and distance information for use by the G N & C computer and for various displays including the Attitude Director Indicator, Horizontal Situation Indicator, and/or CRT displays. In the TACAN mode, the HSI "To/From" indicator and course deviation indicator display deviation from the selected TACAN radial. The HSI course deviation warning flag indicates deviation validity. The desired tacan radial is selected by means of the HSI course set knob and is displayed on the HSI course selector window. Tacan information and HSI selected heading information is routed to the G N & C computer.



TACAN
FIGURE 3.3.4.1.1 (PART I)

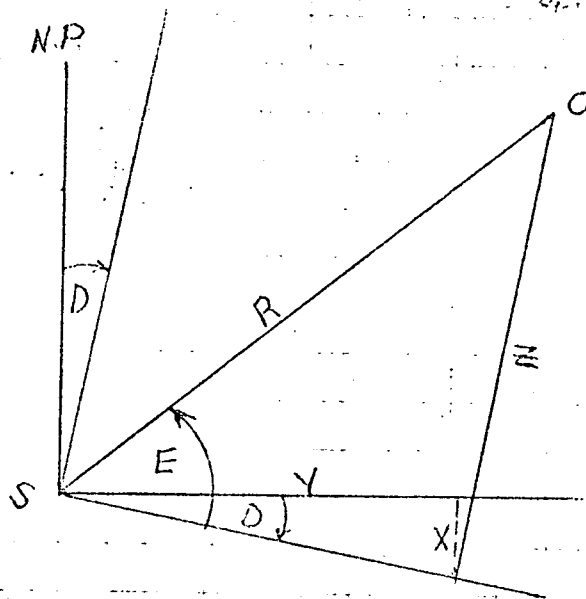


TACAN
FIGURE 3.3.4.1 (PART II)

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Simulation of the TACAN subsystem includes determination of geometry between the orbiter and station selected, signal conditioning and switching logic. Two areas are somewhat, new to training simulations. These are the relatively large area coverage per unit of time and the extreme altitudes involved. In both cases the problem is one of being able to handle a large volume of station data with fast switching. Storage of this data on line would solve the technical problems but would be costly. Using off-line disc or other mass storage media, the problem is one of being able to bring the data on line as a function of switching logic (frequency, antenna selection etc.) and range. The range of trajectories allowable for shuttle missions indicate a requirement for a large number of stations. These stations will be stored off-line. EOM furnished Latitude, Longitude and Heading information will allow ordering the off-line tables in a manner to allow prediction of the area to be covered before the next update of the on-line tables. The on-line tables will be assembled by radio frequency-one set of data for each of the 252 possible selections. The station, for any one frequency, selected to be stored in the on-line table will be the station at the shortest range or strongest received signal. Refer to figure 3.3.4.1.1. As procedures for use of the Tacan become better defined, it may be found that the station data can be assembled from Reset data unique to each reset point. This would be a desirable alternative, however, provision must be made for abort and contingency modes. The latter method should be sufficient for simulation of the orbiter/detached payload mode. In this case, all necessary information can be carried as reset data except for the payload state vector which will be supplied by EOM. Once station unique data is assembled to correspond to the station selected, the simulation is straight-forward. The tacan will be in either search or track mode. In search mode, the bearing (D) will rotate and the range (R) is undefined. In track mode,

the geometry is:



$$D = \tan^{-1} \frac{X}{Y}$$

$$E = \sin^{-1} \frac{-Z}{R}$$

$$R = [X^2 + Y^2 + Z^2]^{1/2}$$

FIGURE 3.3.4.1.2

To this, signal conditioning is applied for range attenuation vehicle attitude (antenna selection), radiation pattern and radio horizon. The visibility due to radio horizon can be expressed as

$$R_h = r_e \frac{\cos E}{\cos (E+B)}$$

where R_h = radio horizon range

r_e = earth radius

E = Elevation angle constraints (default value of zero).

B = central angle between the Tacan station and the orbiter positions

$B = \sin^{-1} (U_{R, \text{Shuttle}} \times U_{R, \text{Tacan}})$

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The test for visibility with respect to the radio horizon between the orbiter and the Tacan station is:

$$R_h < R_{\text{orbiter}} \rightarrow \text{visible}$$

$$R_h > R_{\text{orbiter}} \rightarrow \text{not visible}$$

See figure 3.3.4.1.1

The TACAN simulation will include the "cone of confusion" over the ground station and the built in test checks.

SYMBOL DICTIONARY x_E y_E z_E

Rotating earth centered coordinates of the shuttle vehicle.

 x_{ES} y_{ES} z_{ES}

Rotating earth centered coordinates of the station.

 t_d = Time delay D = relative azimuth angle E = relative elevation angle R = LOS range R_h = radio horizon S_s = Signal strength \vec{A} = Antenna geometry vector

3.3.4.2 ILS Subsystem

The space shuttle ILS subsystem contains triple redundant ILS glide slope, localizer and marker beacon receivers with one frequency selection. The receiver is selected by one of three toggle switch on-off controls which also has test positions. Audio selection is made by one of the same multi-position rotary switch as used for the TACAN subsystem.

Simulation of the ILS subsystem includes geometry of the radiated signal patterns for the localizer glide slopes and the marker beacons. A unique problem to the simulation is the requirement for two nominal glide slopes, simulated simultaneously. These will have slopes of approximately 8° and 15° . The problem is not totally new since standard glide slopes have nulls at the nominal angle E , $2E$, $3E$, $4E$, and $5E$ with the $5E$ signal phasing the same as E (fly-to error signals). The system concept depicted in Figure 3.3.4.2.2 includes these unique features, as well as the standard geometry and switching problems which must be solved. The geometry is:

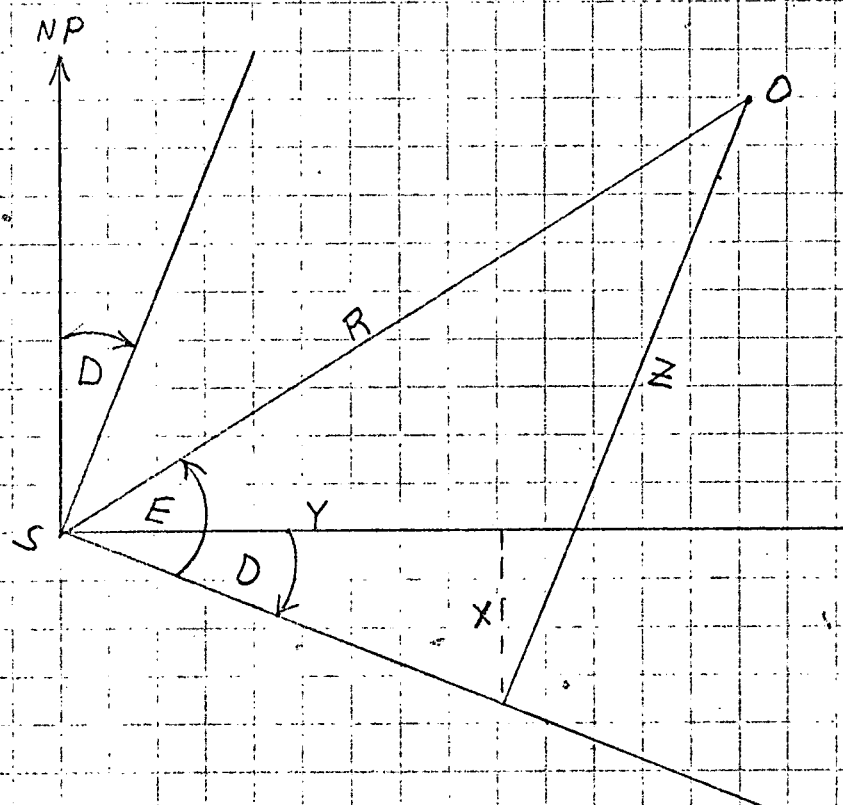


Figure 3.3.4.2.1

ILS Geometry

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where the station azimuth angle relative to earth north is $\tan^{-1} \frac{\Delta X}{\Delta Y}$. The station-to-orbiter elevation angle is defined by the angle $\sin^{-1} \frac{\Delta Z}{R}$. An additional conditioning of the elevation error signal is required due to the multi-lobe radiated pattern and distortion of the radiated signal due to local geography and weather. The error signals generated are fly-to for the E and 5E cases and fly-from otherwise with nulls at 2E, 3E and 4E. The 8° and 15° glide slopes are assumed nominal for prime and selected alternate landing sites for the shuttle. Any other landing site would require using the 5E lobe null (with a nominal E of ~3° for the steep glide slope). The simulation concept allows the instructor options for selection of these conditions either for space or ferry missions. Station audio identification is generated and routed to the communications system for both the ILS station and ident codes for each of the marker beacons. Aircraft systems have an indicator lamp which flashes the marker beacon code. This lamp is not known to exist on the shuttle panels, but may be part of a CRT display.

Number of Equations: 50

Equation Loop Factor: 3

Iteration Rates: 10/sec.

Accuracy Requirements: 15 bits

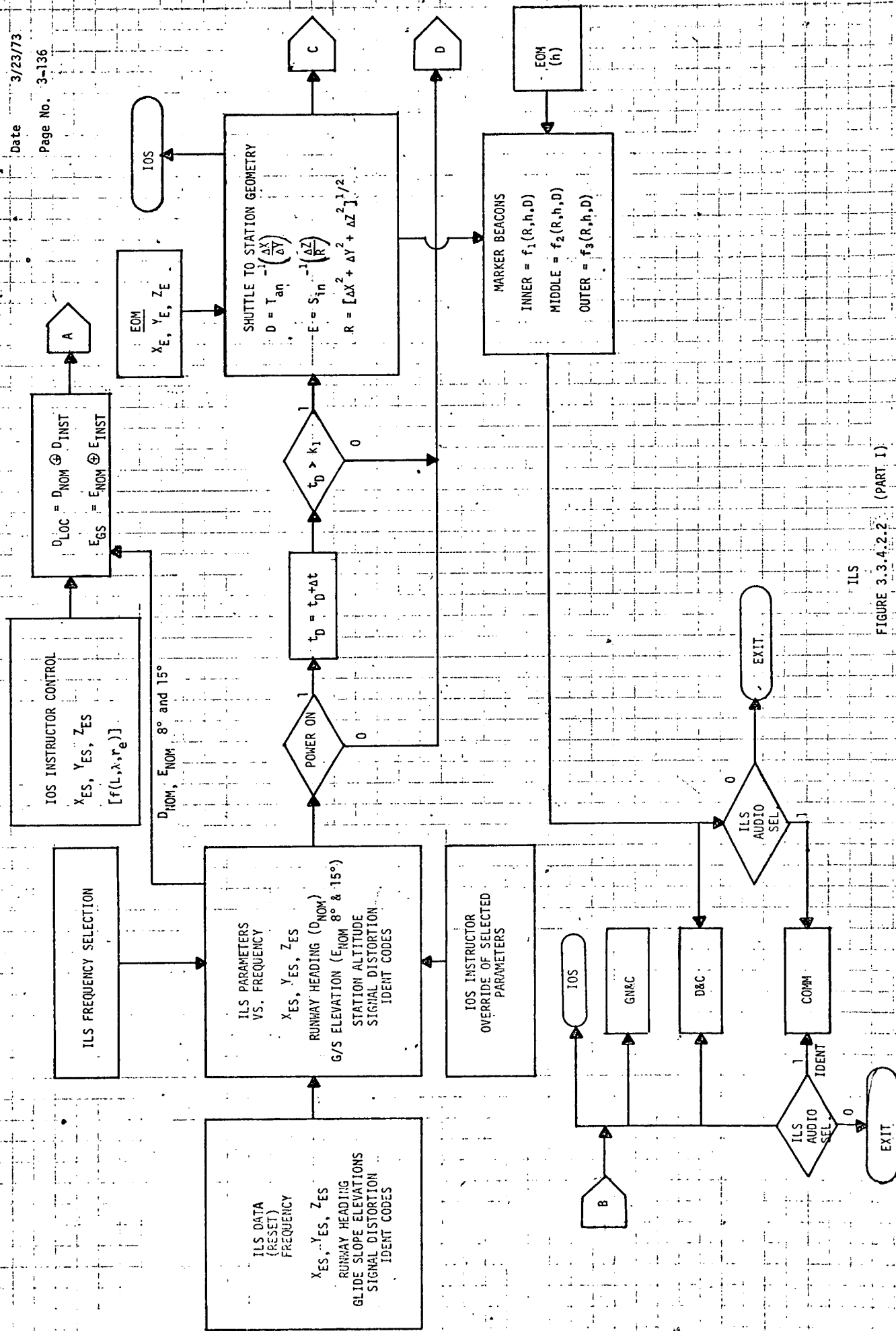
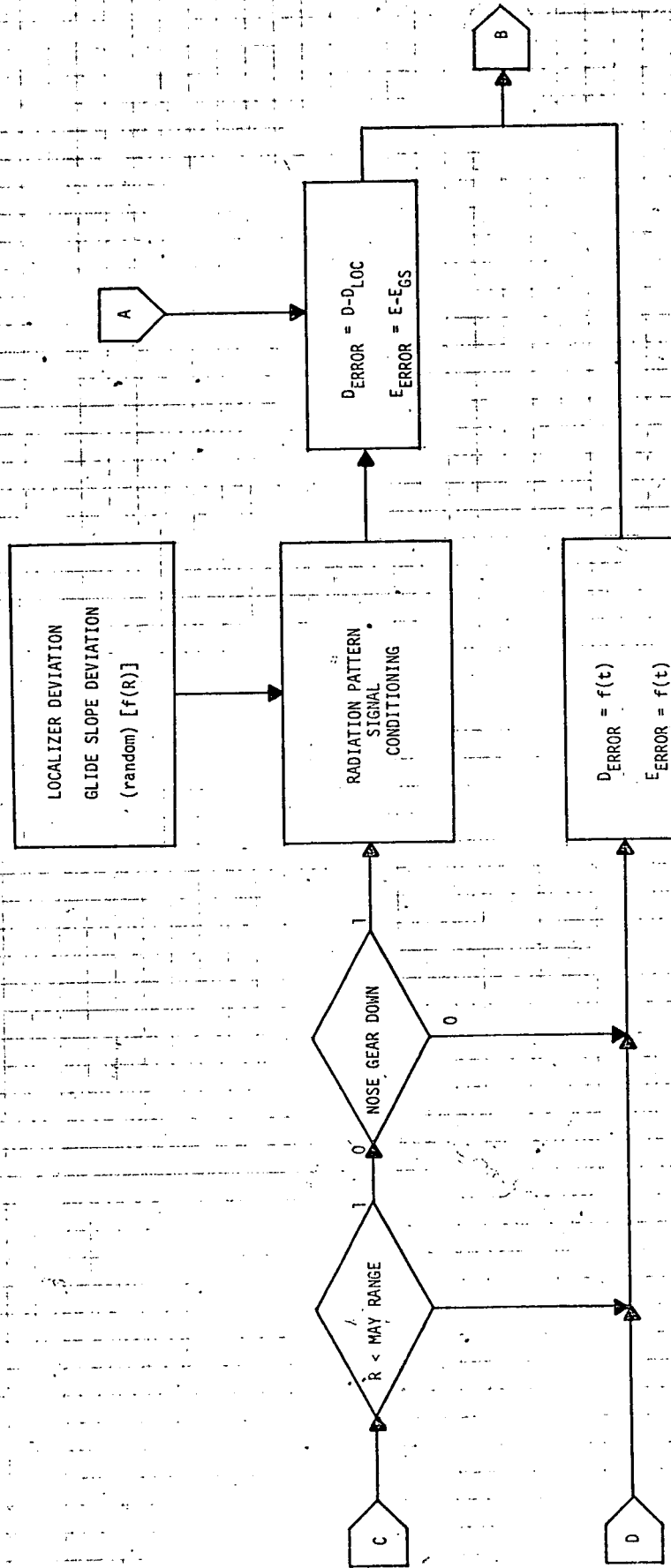


FIGURE 3.3.4.2.2 (PART 1)



ILS

FIGURE 3.3.4.2.2 (PART II)

3.3.4.3 Navajds Radar Altimeter Subsystem

A typical FAA radar altimeter is assumed. This subsystem will provide warning cues as well as an accurate measurement of vehicle altitude above local terrain for display and inputs to the GN&C, COMM and D&C systems. The antennae are located sufficiently close to the vehicle center of gravity that no apparent change in indicated altitude occurs with vehicle attitude changes. Gross attitude change can, however, cause a loss of return. The logic functions shown are typical.

A local terrain software model will be constructed and data specified at the intersection of azimuth radials and range circles centered at the runway. Linear interpolation between data points will provide a smooth change in terrain altitude with the values in the tables representing exact terrain altitude at the specific points. Simulation requirements indicate a requirement for maximum accuracy at touchdown and near the nominal approach azimuth. Lower accuracy can be tolerated at long range from the landing site and at large relative bearings to the runway leadings.

Symbols and Definitions

[B-E] B to E frame direction cosines

WOW Weight on wheels

WDL Wheels down and locked

h Altitude

k constant

h_R Radar altitude

r Vehicle radius to center of earth

r_0 Nominal earth radius distance exclusive of local terrain

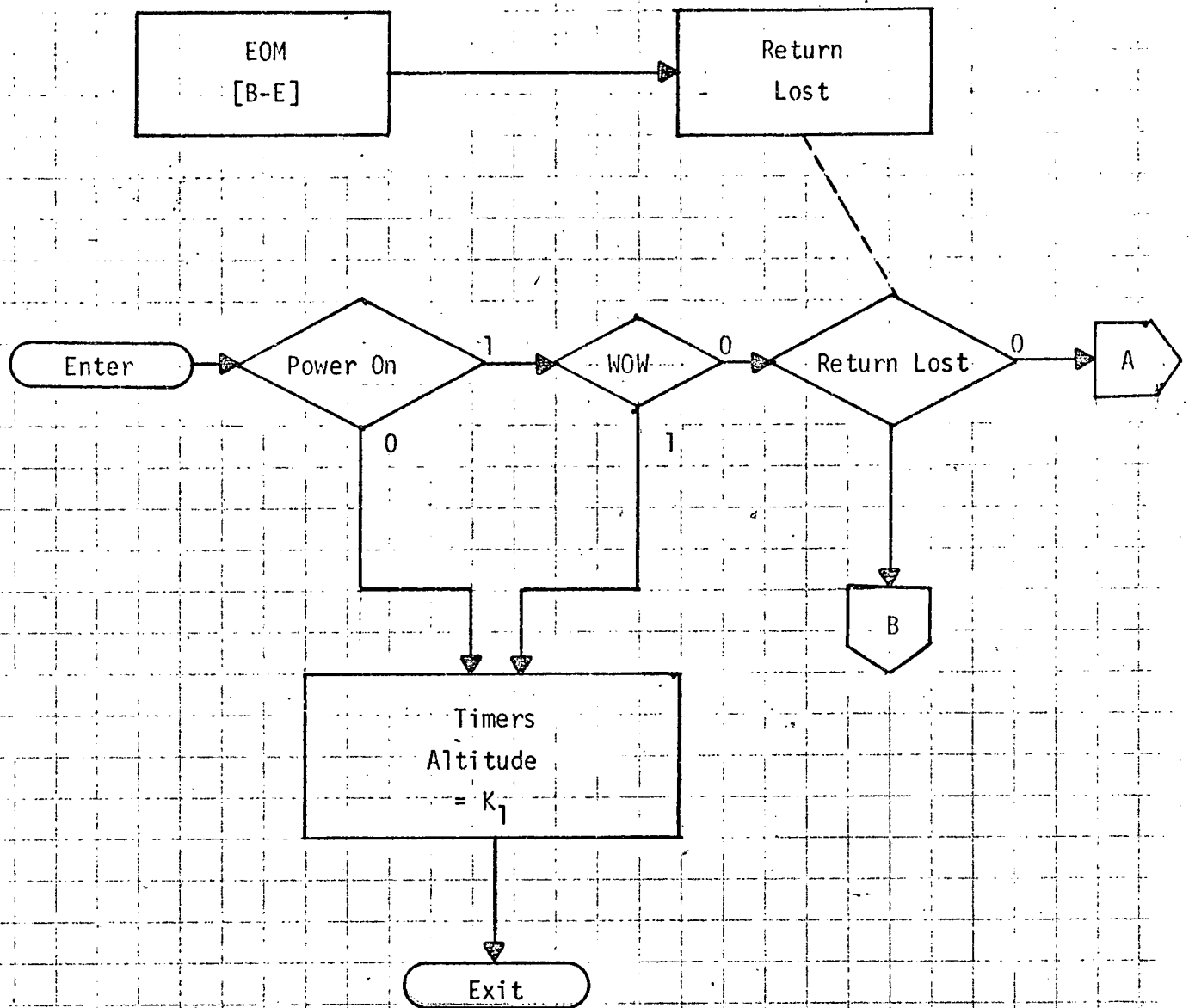


Figure 3.3.4.3 Radar Altimeter

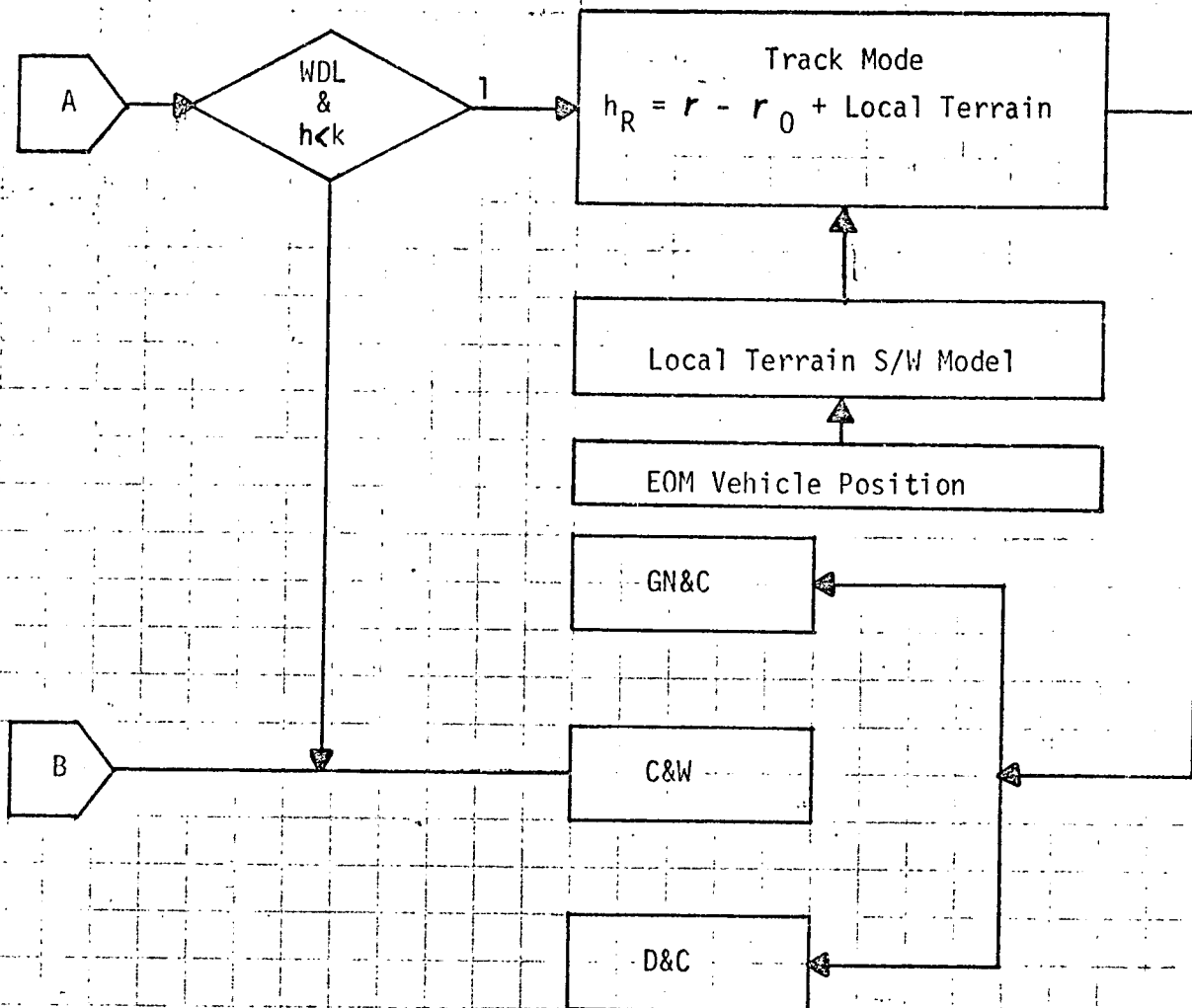


Figure 3.3.4.3 Radar Altimeter

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3.3.4.4 ATC Transponder

The ATC Transponder system consists of the flight transponder with an on-off toggle switch and a toggle switch selection for transponder #1 and #2. The simulation will consist of monitors for these switches at the Instructor-Operator Station. Refer to Figure 3.3.4.4.

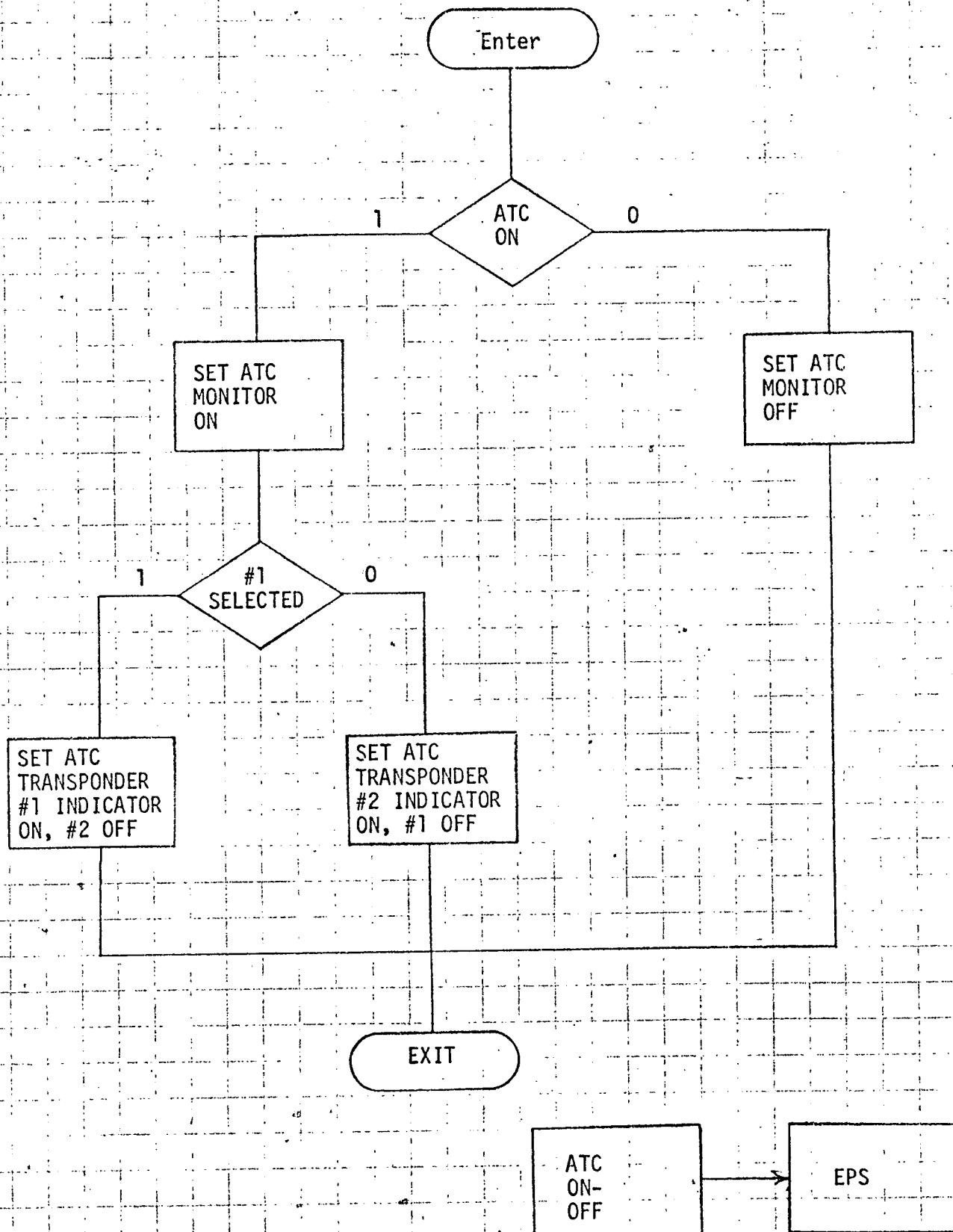


Figure 3.3.4.4

3.3.4.5 NAVAIDS MICROWAVE LANDING SYSTEM (MLS)

The requirements of the MLS are essentially the same as for ILS (paragraph 3.3.4.2). The major differences are station frequency, orbiter controls, greater accuracy of steering information and shorter range. The conceptual design is essentially that shown for the ILS in figure 3.3.4.2. Requirements for an MLS system have not been firmly established, however the system is included in the SCD because of the probable need for a system with higher accuracy than the conventional ILS system for autoland requirements.

3.3.4.6 S-Band Communication Subsystem

The simulation of the S-Band voice, data, and command communication link will be modeled by calculating the signal strength of the received signal at the vehicle and the transmitted power level. To determine the signal strength, it is necessary to determine if the signal path is occulted by earth.

The number of stations that must be tested are limited to the STDN and SGLS stations.

As shown in Figure 3.3.4.6, the line-of-sight acquisition is calculated from the vehicle position vector from EOM. Only those stations having positive elevation angles are acceptable as having line-of-sight.

The transmitter and receiver operational power is calculated from EPS power available booleans, circuit breaker state, and switch state in the crew station. Switching logic will be taken into account by the program.

Transmitter signal strength is calculated using transmitter output power attenuation losses to the antenna, and antenna gain. The transmitting-receiving antenna is determined by calculating the receiver signal strength at all antennas. In auto switching mode, the antenna with the highest signal strength is selected. This is accomplished by computing the mode of antenna selection as based on the crew panel switch positions and the calculated AGC voltage. The attenuation of the incoming signal is calculated from the attenuated ground transmitter power and the attenuation pattern of the signal from the selected antenna. The antenna pattern attenuation is calculated by performing a vehicle to Earth transformation of the EOM data yielding the relative position of the ground site to the vehicle antenna.

Following calculation of the attenuation, a background noise level will be calculated and a signal level will be calculated. These two signals will be furnished to the audio hardware equipment to generate a voice volume and a noise

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volume level. Instructor override of the volume level calculated by the program will be provided.

Booleans will be generated signifying that T/M and/or DCS command capability exists. These booleans will be provided to MCC and to using subsystems.

Simulation of the phase-lock S-Band Ranging system will be provided by calculating the distance of separation of the vehicle from the ground station. This function will not require "ground station" processing by computer. The range calculated will be made available to MCC for all stations in contact with the vehicle.

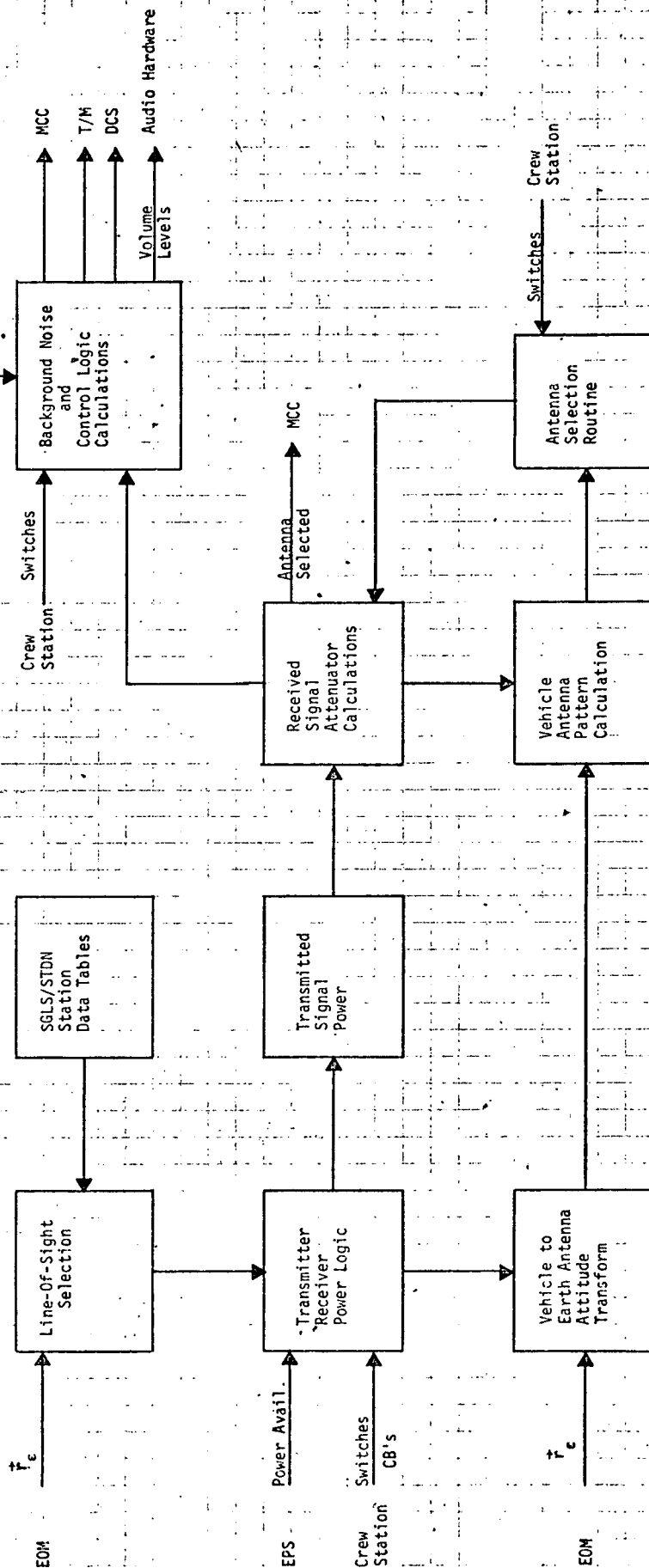


Figure 3.3.4.6

S-BAND COMMUNICATION SYSTEM

3.3.4.7 UHF Communication Subsystem

The simulation of the UHF transceiver voice communication link will be modeled by calculating the signal strength of the received signal and the transmitted power level. To determine the signal strength, it is necessary to determine if a station is occulted by earth and is operating on the correct frequency.

The number of possible stations that may be tested is limited by computer time and core. At high orbital altitudes, it becomes possible for the vehicle to have line-of-sight with large earth surface areas. The extreme example is that an area greater than the U.S. may be within line-of-sight. With such coverage, it is necessary to limit the number of ground stations loaded in working core of the computer. At this time, it is felt that twenty-five additional stations over the normal STDN stations are sufficient for any training mission. To bring these stations into core, one concept that is usable is to use the Reset feature to call from mass storage twenty-five UHF stations' parameters. Additions or deletions may be made to the Reset selected stations by providing to the instructor controlled access to the mass memory tables. These mass memory tables are expected to require approximately one-thousand stations' parameters.

In Figure 3.3.4.7, the first step in solving the UHF communication model is to calculate accessibility of line-of-sight. This is accomplished by computing the elevation angle of the vehicle. Only those stations having positive elevation angles for the vehicle are selected as having line-of-sight.

From these selected stations, the frequency (or channel) set on the crew station panels will be used to further edit the non-active stations from

the stations with positive elevation angles. Once a ground station has been identified as having both a positive elevation angle and on the same frequency as the vehicle, the station identification code, position of station in the E-frame, and the station transmitted power are provided to the transceiver power logic equations.

The transceiver power logic equations generate booleans for receiver-on and transmitter-on from the EPS power-available booleans and the crew station switch and circuit breaker control logic.

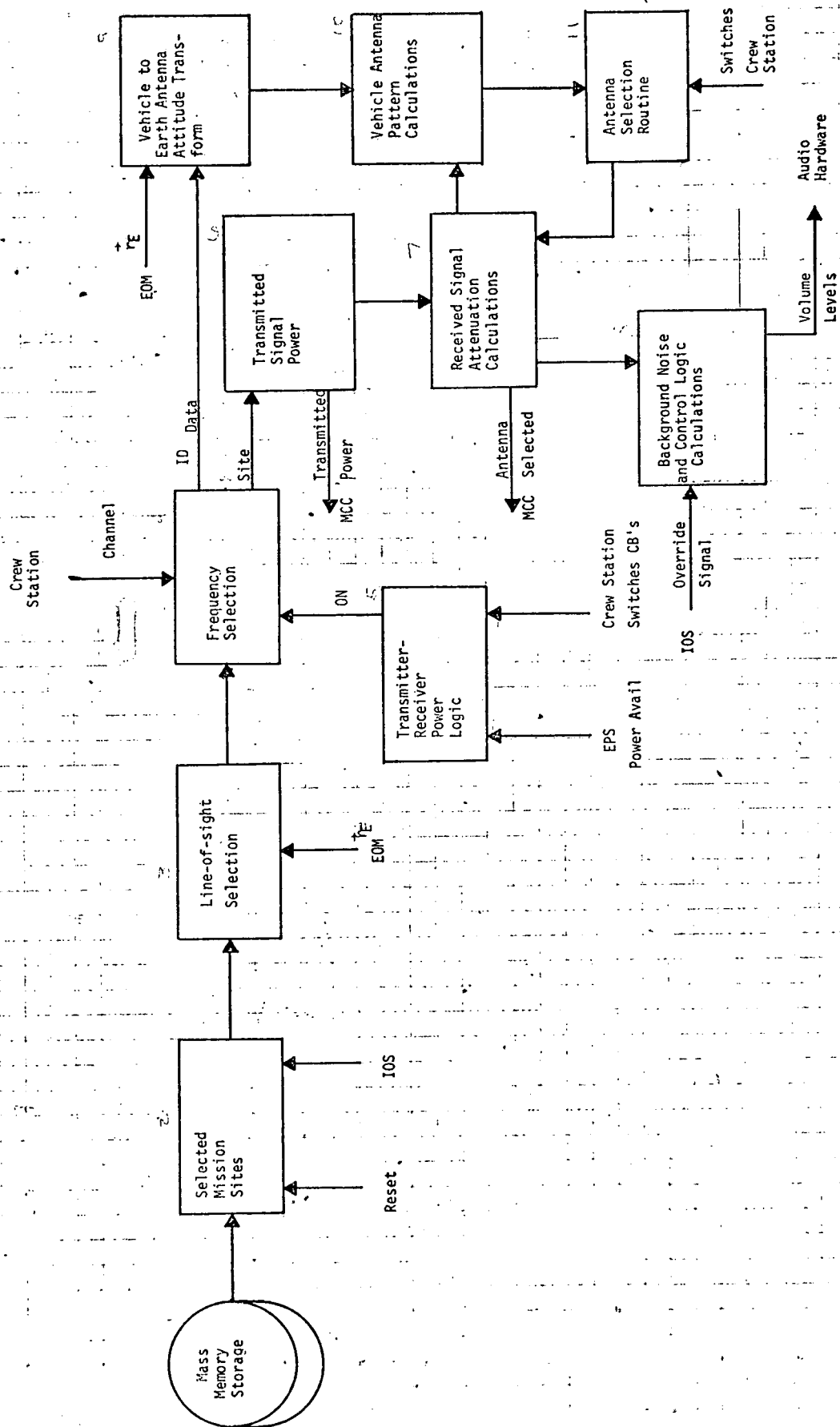
Transmitter signal strength is calculated using transmitter output power attenuation losses to the antenna, and antenna gain. The transmitting-receiving antenna is determined by calculating the receiver signal strength at all antennas. In auto switching mode, the antenna with the highest signal strength is selected. This is accomplished by computing the mode of antenna selection as based on the crew panel switch positions and the calculated AGC voltage. The attenuation of the incoming signal is calculated from the attenuated ground transmitter power, and the attenuation pattern of the signal from the selected antenna. The antenna pattern attenuation is calculated by performing a vehicle to Earth transformation of the EOM data yielding the relative position of the ground site to the vehicle antenna.

Following calculation of the attenuation, a background noise level will be calculated and a signal level will be calculated. These two signals will be furnished to the audio hardware equipment to generate a voice volume and a noise volume level. Instructor override of the volume level calculated by the program will be provided.

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3.3.4.8 Telemetry Subsystem

The Telemetry Subsystem for the Shuttle is simulated by supplying the GSSC-MCC complex with a serial digital data stream in a format. At this time, it is assumed that the format required by MCC for integrated training will be the same as would be received at MCC in the real-world situation. The format of the multiplexed air-to-ground station telemetry data will be simulated within the main computer for display and malfunction purposes. This assumption is based on previous simulation experience from SLS and CMS.

The vehicle for both OFI and DFI has a maximum data transfer rate of 128 Kbps on 1.024 MHz and 256 Kbps on 1.7 MHz. The 128 Kbps is apparently dedicated to the vehicle operation plus payload interface parameters. The 256 Kbps is payload dedicated.

The T/M simulation design concept is limited to present day equipment by NASA decision. This equipment allows a maximum Building 30 - Building 5 interface rate of 51.2 Kbps on each of two coaxial lines. This limitation reduced the T/M interface to 51.2 Kbps for the OFI and DFI instrumentation and to 51.2 Kbps for the payload digital data. The 51.2 Kbps rate is used for the two line links because the existing equipment has been used at that rate previously in the CMS Trainer.

The telemetry program functions are shown pictorially in Figure 3.3.4.8. The multiplexer power logic equations calculate the operating condition of the multiplexer and the signal conditioning units. The telemetry data will be transferred to GSSC even when the simulated T/M transmitter is inoperable. Additional booleans will be supplied to GSSC indicating the operating condition and power output of each transmitter unit from the S-Band System equations.

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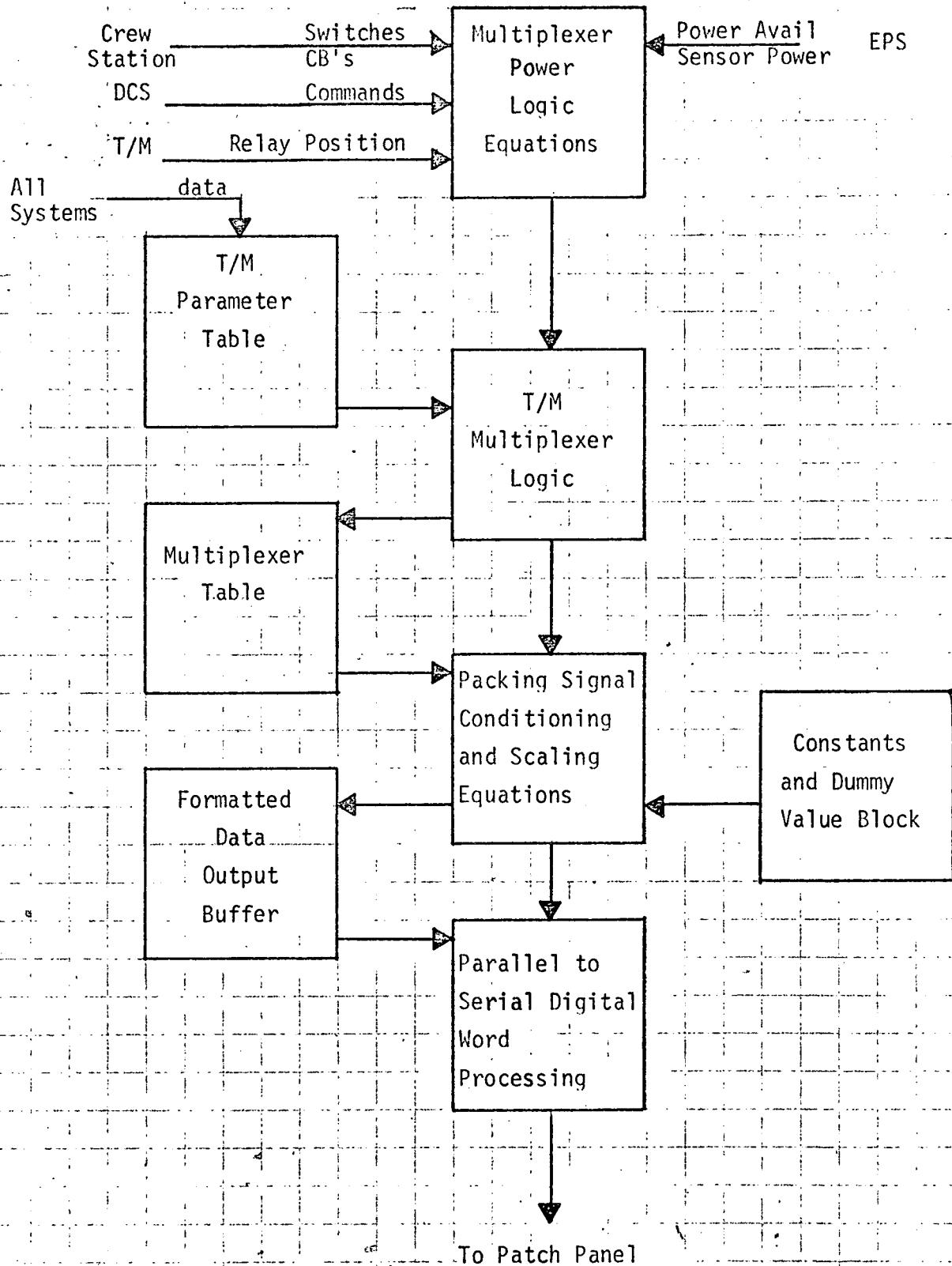
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Telemetry parameters generated by the software systems will be stored into a table where the T/M multiplexer equations will condition the inoperative multiplexer channels with dummy values. These generated T/M multiplexer tables are then processed by the signal conditioning and scaling program. This program will take the digital floating point values and convert the data to packed words or biased, scaled, fixed point data values. These new values will then be stored into a format with the dummy filler values and constant values.

Figure 3.3.4.8 Telemetry System



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3.3.4.9 Digital Command Subsystem

The Up-Link Digital Command Subsystem is simulated by use of software and hardware for the transmission of command data.

In the integrated mode with MCC, an encoded word will be generated by the controller, shipped by hardware telephone equipment to the SMS computer. Within the computer, software will decode the command, set a boolean indicating the command, and generate a boolean for T/M of acceptance of the DCS command.

For the non-integrated mode of computer operation, the instructor will provide up-data commands by manual insertion using the CRT or other means of data entry.

If the advanced training technique of predetermined instructor action is implemented, it will be possible for the remote commands to be established by the computer similar to malfunctions.

The software required is shown in Figure 3.3.4.9. The incoming command word from MCC or the IOS is decoded if the power switching logic equations show that the S-Band receiver has acquired the ground signal in sufficient strength to receive messages, that EPS power is available to the DCS decoder via switches and circuit breakers, and the decoder is operational. The decoder will test the incoming message and store a boolean in the selected command word location and establish a boolean for the T/M program to transmit signifying command message acceptance.

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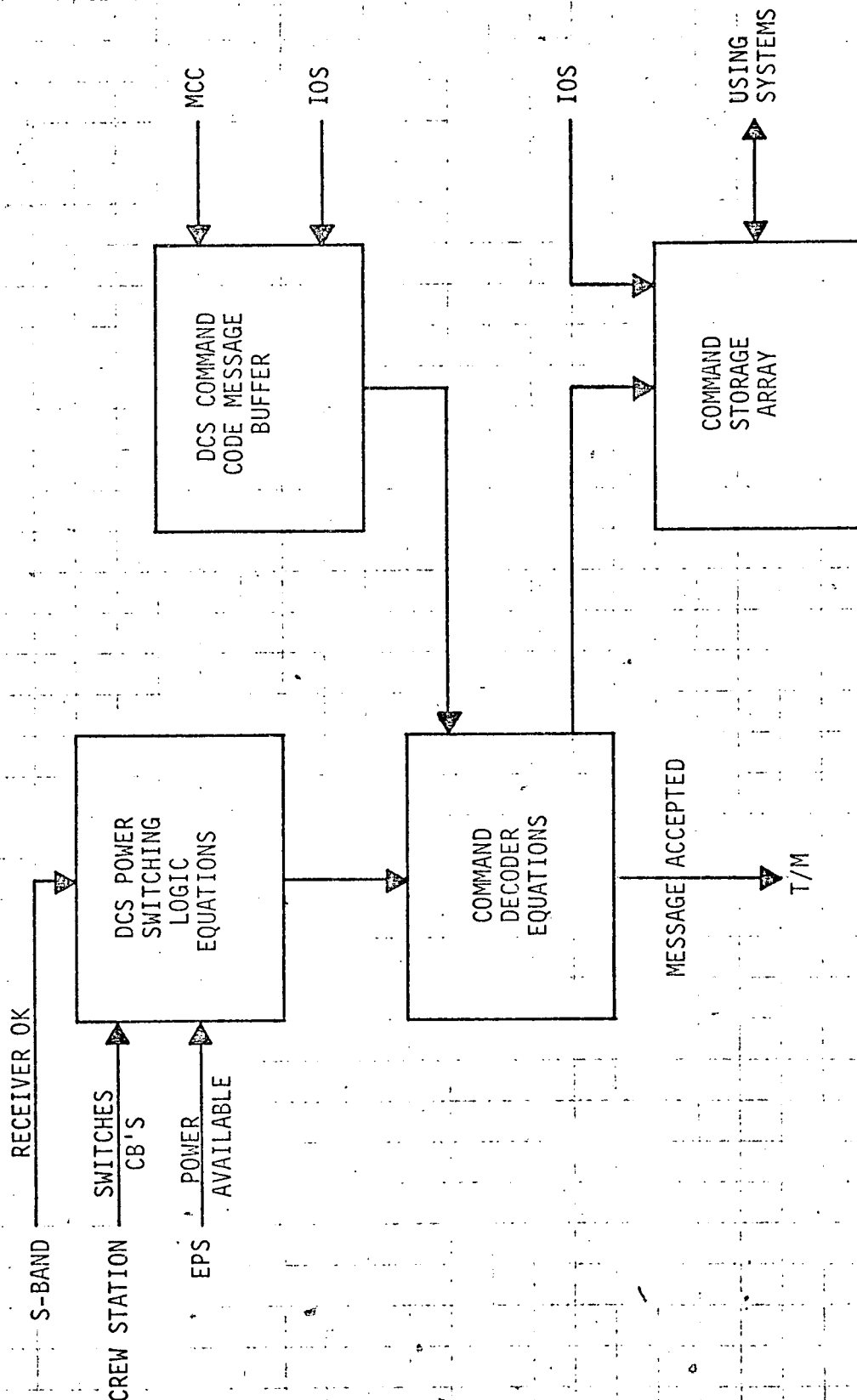
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3.3.4.9 Digital Command System

3.3.4.10 Television Control Logic Subsystem

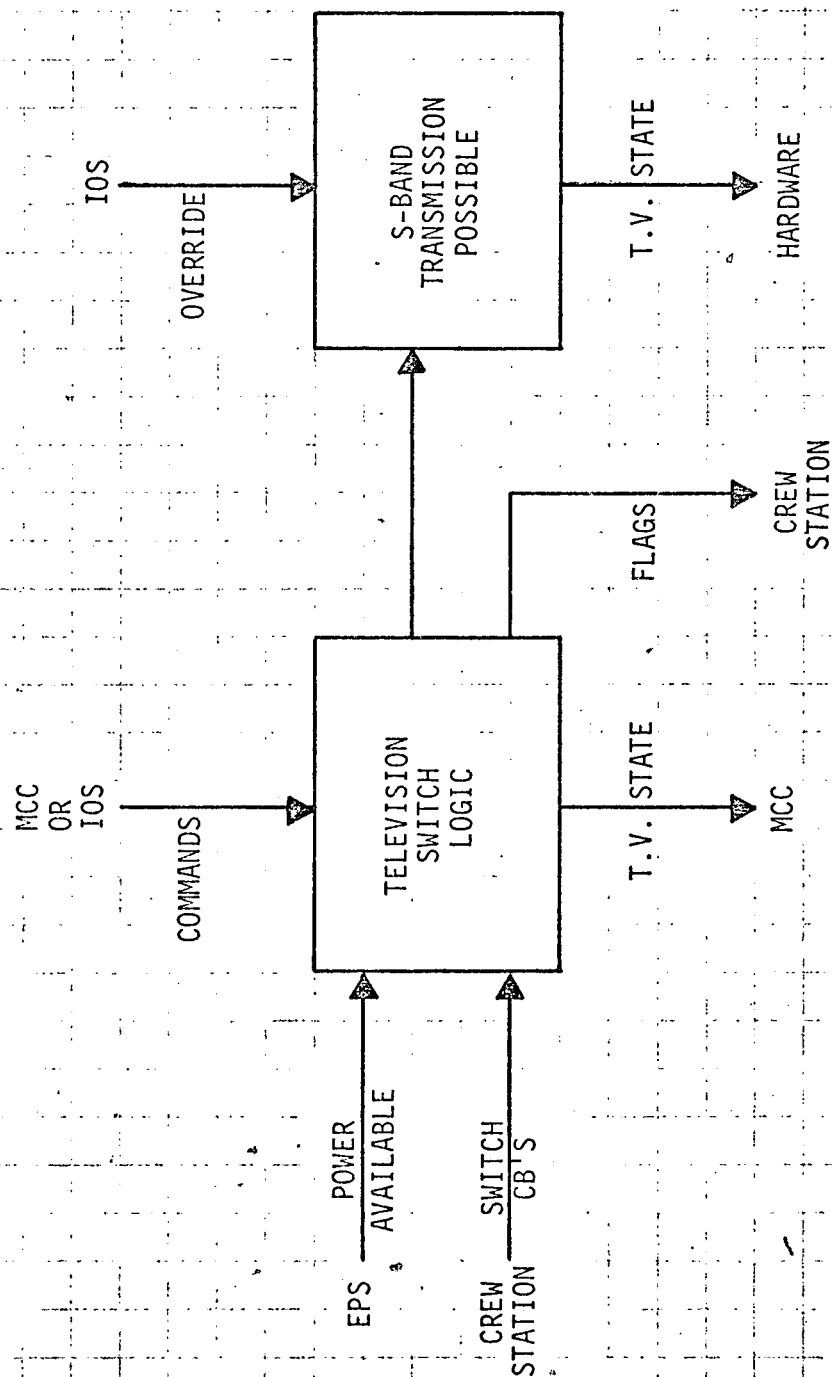
The software simulation of the TV Subsystem will provide the switching and relay logic of the on-board television cameras and monitors. Crew station switch position, circuit breaker position, and remote DCS commands will be included in the equations to determine camera power and receiver power. A test will be made of the S-Band transmitter power level to determine if air-to-ground transmission is possible. A test will also be made on the S-Band received signal to determine if airborne reception is possible.

The IOS will be provided with a remote TV monitor simulating the vehicle monitor or the ground monitor station. Provision shall be made for instructor override over the S-Band signal attenuation and crew station power logic.

3.3.4.11 Recorder Control Logic Subsystem

The software simulation of the Voice Recorder will provide the switching and relay logic of the audio recorder. Crew station switch and circuit breaker position will be included in the equations to determine recorder power. Discretes will be provided to determine whether the recorder is in record, rewind, or playback.

The software simulation of the Data Recorder will provide the switching and relay logic of the data recorder unit. Crew station switch and circuit breaker position will be included in the equations to determine recorder power. Discretes will be provided to determine whether the recorder is in record, rewind, or playback.



3.3.4.10.-1 TELEVISION CONTROL LOGIC

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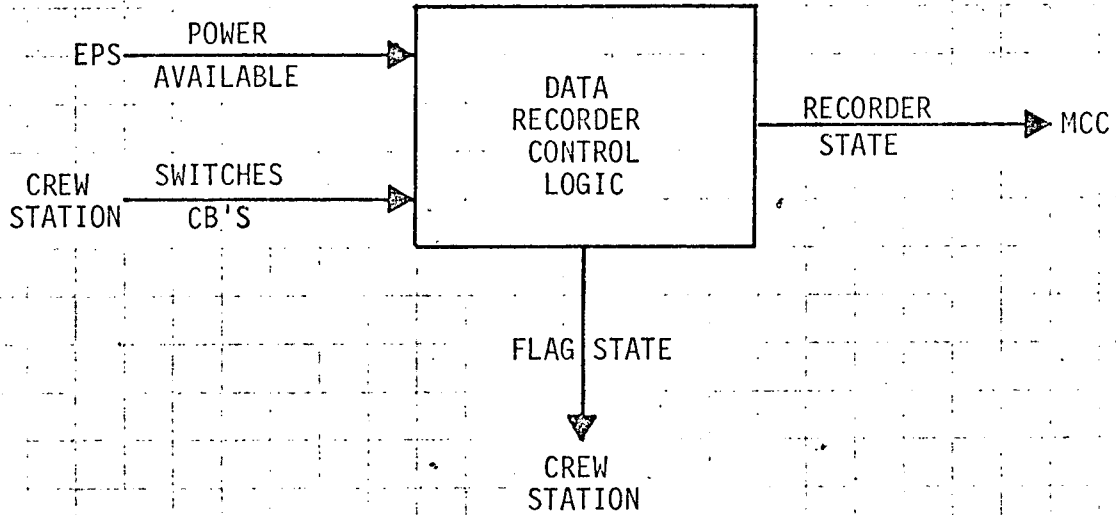
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3.3.4.11.-1 Data Recorder Control

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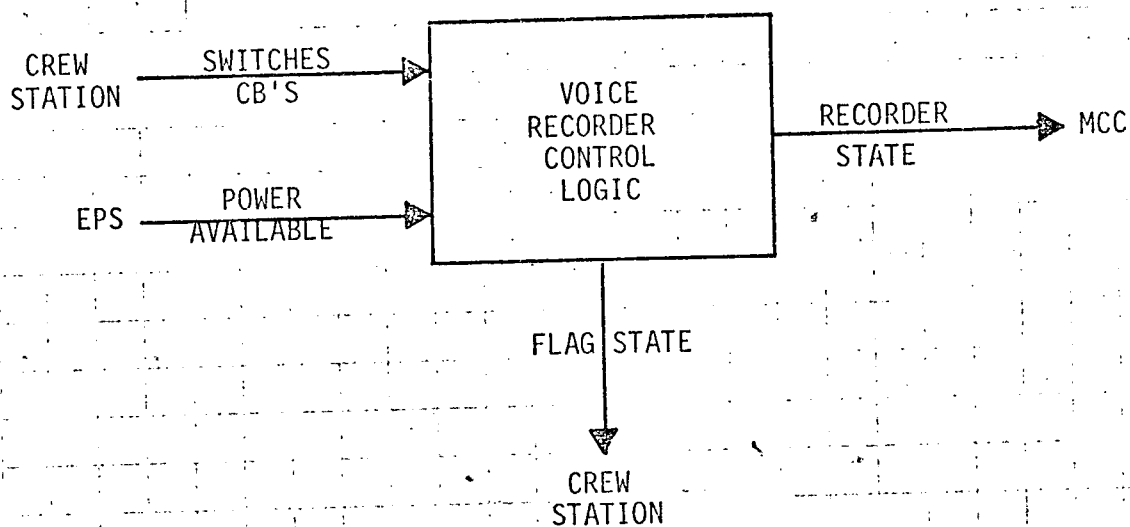
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3.3.4.11.-2 VOICE RECORDER CONTROL

3.3.4.12 VHF Communication Subsystem

The simulation of the VHF duplex and simplex voice and data communication link will be modeled by calculating the signal strength of the received signal from the ground stations and the transmitted power level out of the vehicle antennas to the ground station. To determine the signal strength, it is necessary to also determine if a station is occulted by the earth and if it is operating on the correct frequency.

The number of possible stations that have line-of-sight coverage is excessive when it is considered that the area of coverage may be as large as the United States. With such coverage, it is necessary to limit the number of ground stations loaded in working core of the computer. At this time, it is felt that twenty-five additional stations, over the normal STDN stations, are sufficient for training. The Reset feature as described in the UHF Logic System will be used.

The process of identifying those stations having line-of-sight, on correct frequency, receiver-transmitter operation, receiver-transmitter signal strength, and signal-to-noise ratio, is the same as the UHF Logic System for simulation concept. This process is identified as the signal-to-noise equations in Figure 3.3.12.3.

Following the station-to-vehicle calculations, the equation:

$$\frac{|\vec{r}|^2 - \vec{r} \cdot \vec{r}_{TV}}{|\vec{r} - \vec{r}_{TV}|} < |\vec{r}|^2 - r_E^2$$

where: \vec{r} = Orbiter vector - Earth-centered Inertial

\vec{r}_{TV} = Target Vehicle vector - Earth-centered Inertial

r_E = Earth radius (assumed spherical model)

solves the problem of line-of-sight from orbiter-to-target vehicle.

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The attenuation of the signal paths between the two vehicles will then be calculated based on antenna pattern orientation and vehicle separation distance. The relative bearing angles will be calculated and applied to equations representing the antenna pattern.

Using the attenuation figure for the target vehicle to the shuttle, a boolean will be established for the condition of reception of data of the low 2Kbs rate.

From the attenuation figure for the orbiter to target vehicle, a boolean will be established for the condition of transmission of commands.

Booleans representing the capability to transmit or receive voice will be generated by the programs for use by the audio hardware.

VHF LOGIC SYSTEM

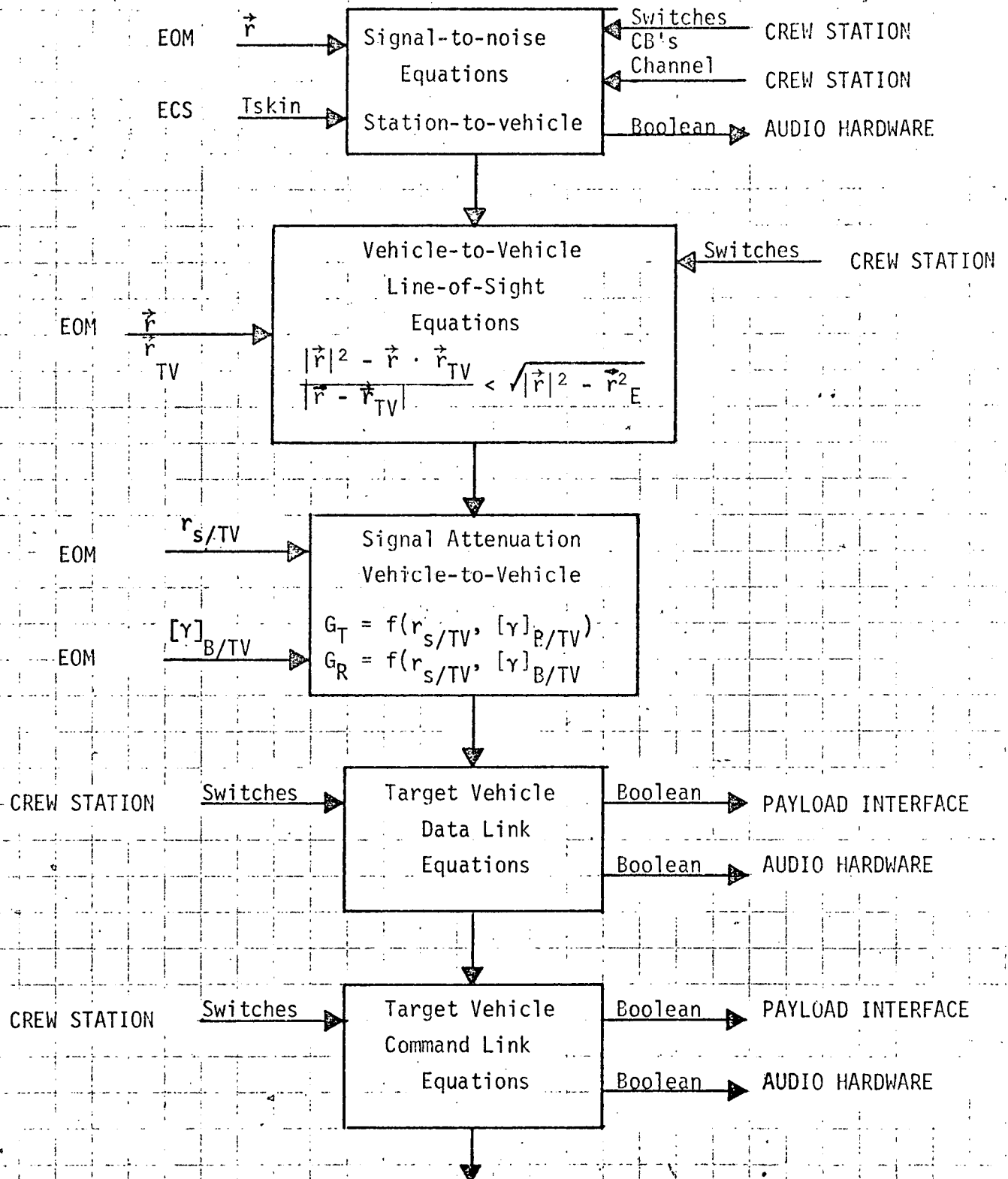


FIGURE 3.3.4.12

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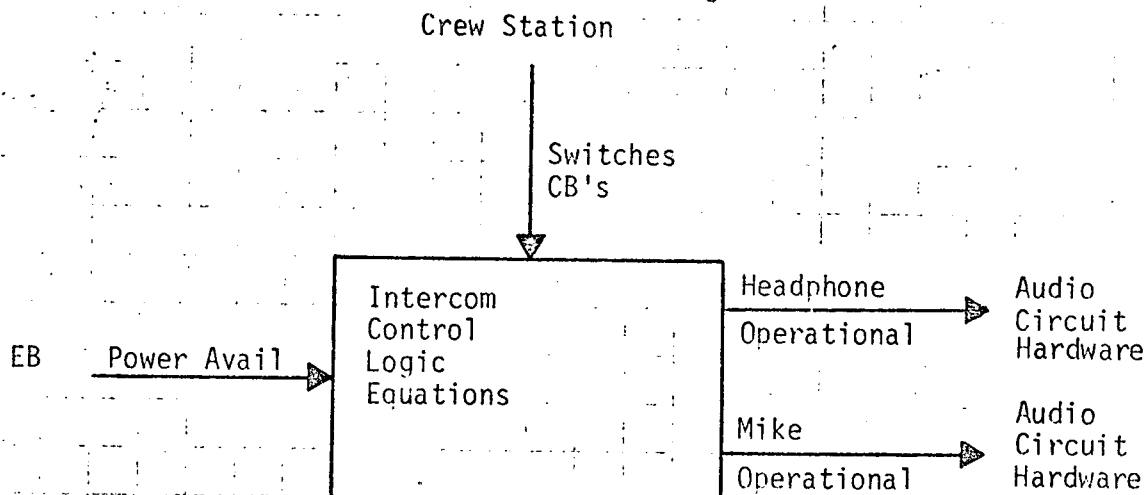
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3.3.4.13 Intercom Switching Subsystem

The intercom or audio control logic will be simulated for all relay and switching logic by software. Inputs to the logic equations will be provided by the crew station switches and circuit breakers. All real-world electronic relay circuits or logic circuits will be modeled by software equations with malfunctions. Physical control of the voice and noise level on each circuit will be provided by the originating system.

Figure 3.3.4.13 Intercom Control Logic

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3.3.4.14 Wide Band Data Link Subsystem

The simulation of the Wide Band transmission of main engine and payload data is not justifiable using existing data lines and equipment. The major problem is that the type of data being transmitted over wide band requires either analog simulation or a very high rate (1,000 samples per second) of digital simulation. There are not enough coax lines to transfer analog data for approximately 50 channels of data. There are coax cables which could transmit 51.2 Kbs of data; however, a digital simulation with an iteration rate of 1,000 cycles per second would be required. This framing rate would require a specially dedicated computer. This method is possible; however, it is felt the cost of this method would prohibit the value derived from transfer of the data to MCC.

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3.3.5 Control and Display

3.3.5.1 Caution and Warning Subsystem

The Caution and Warning Subsystem is suitable for a logic equation simulation. The system is composed of four types of crew cues: alert, caution, warning, and emergency. All four have one common identity - the audio cues. The simulation can be best approached by the division of equations shown in Figure 3.3.5.1.

The Alert power and display logic equations determine if alert power is available, whether the sensors are active, and generates booleans for display in the crew station when input parameters are out of tolerance. A boolean will be generated for cue to the audio device each time a new parameter is sensed out of tolerance.

The Caution and Warning Power equations simulate the separate internal power supplies of Caution power and Warning power. Since these units are controlled by the same switch, circuit breaker, relay functions, they are included together. The equations generate Caution sensor power available and Warning sensor power available booleans to the using subsystem.

The using subsystems will include the sensor power available term in their equations prior to input to the Caution and Warning System. The inputs are to be tested against stored upper and lower value limit tables in the parameter test equations. Discretes will be generated for each parameter out of tolerance for display in the crew station. In addition a boolean will be generated as a cue to the audio alarm equations each time a new Caution or Warning parameter is found to be out-of-tolerance. Crew station inhibit switches are to be included in the logical test so that discrete alarms can be isolated.

The Emergency power equations simulate the emergency power unit and its control switches and circuit breakers. An emergency sensor power available boolean will be generated by the equations for inclusion in equations of the using subsystems. Inputs for Emergency alarms from the using systems will then be tested against upper and lower limits in the emergency parameter test equations. The test equation will take into account the crew station inhibit switch position.

Booleans generated by the alert, caution, warning, and emergency equations will be included in equations in the audio alarm section to provide cues to the audio devices as to which alarms are on. Volume control of the intercom speakers for the alarms will be a hardware control.

The instrumentation signal conditioning of Caution and Warning Subsystem parameters will be accomplished using sensor and display logic booleans from the Electrical Power Subsystem for crew station display, for reinput to the Caution and Warning Subsystem, or for input to the Telemetry Subsystem Multiplexer Program. The equations of the Caution and Warning Subsystem will be repeated for each unit, either by programmed loops or by repetitive equations, whichever requires the least amount of computer time and core. Required malfunctions for the Caution and Warning simulation are to be designed into the simulation for minimum computer impact.

The diagram illustrates the Alert Power and Display Logic Equations system. It shows the flow of data and control signals between various components and systems.

Input Systems and Signals:

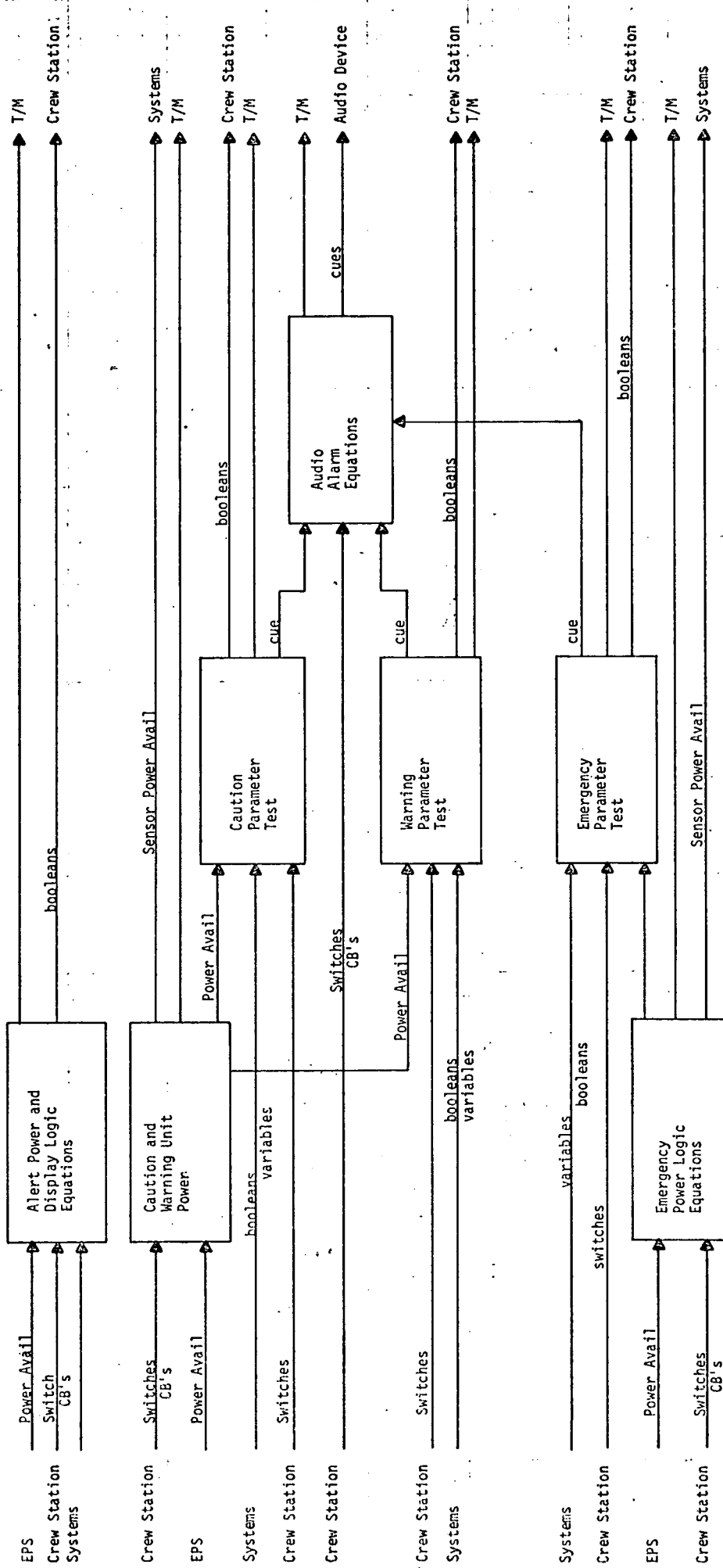
- EPS:** Provides **Power Avail** and **Switches CB's** to the **Alert Power and Display Logic Equations** block.
- Crew Station:** Provides **Switches CB's** and **Power Avail** to the **Cautious and Warning Unit Power** block.
- Systems:** Provides **Switches** to the **Cautious and Warning Unit Power** block.

Processing Units and Internal Signals:

- Alert Power and Display Logic Equations:** Receives inputs from EPS and Crew Station. It outputs **boolean's** to the **Crew Station** and **T/M**.
- Cautious and Warning Unit Power:** Receives inputs from Crew Station and Systems. It outputs **boolean's** to the **Crew Station** and **Systems**, and **Power Avail** to the **Cautious Parameter Test** block.
- Cautious Parameter Test:** Receives **Power Avail** from the Cautious and Warning Unit Power. It outputs **boolean's** to the **Crew Station** and **Systems**, and **cue** to the **Audio Alarm Equations** block.
- Warning Parameter Test:** Receives **Switches CB's** from the Crew Station and **Power Avail** from the Cautious and Warning Unit Power. It outputs **boolean's** to the **Crew Station** and **Systems**, and **cue** to the **Audio Alarm Equations** block.
- Emergency Parameter Test:** Receives **boolean's** from the Crew Station and **cue** from the Warning Parameter Test. It outputs **boolean's** to the **Crew Station** and **Systems**.
- Audio Alarm Equations:** Receives **cue** from the Cautious Parameter Test and **cue** from the Warning Parameter Test. It outputs **boolean's** to the **Crew Station** and **Systems**, and **cues** to the **Audio Device**.

Output Systems and Signals:

- Crew Station:** Receives **boolean's** from the Alert Power and Display Logic Equations, Cautious Parameter Test, Warning Parameter Test, and Emergency Parameter Test. It also receives **Power Avail** from the Cautious and Warning Unit Power.
- Systems:** Receives **boolean's** from the Alert Power and Display Logic Equations, Cautious Parameter Test, Warning Parameter Test, and Emergency Parameter Test. It also receives **Power Avail** from the Cautious and Warning Unit Power.
- Audio Device:** Receives **cues** from the Audio Alarm Equations block.



3.3.5.2 Supplementary Display (IOS)

The IOS will be provided with real-time software controlled CRT displays. The following display descriptions are considered as desirable instructor aides, however the design will be highly dependent on the final hardware selection.

For prelaunch, a display will be provided for the Ground Support Checkout function. This display will be a functional simulation of the interface performed by GSE equipment and will allow the instructor to monitor the launch vehicle similar to the GSE monitor.

Telemetry displays will be provided by both simulated on-board systems and by the T/M Multiplex program for both integrated and non-integrated training with the Mission Control Center.

A display will be provided to generate a presentation for a Ground Controlled Approach simulation. Because there is no requirement to train GCA controllers or instructors as controllers, the presentation will be in the form of digital correction for the instructor to communicate to the pilot. This would simulate a GCA landing.

An FAA tracking radar coverage could be generated for training pilots in flight pattern in air corridors and flight traffic holding patterns.

A graphic terminal display of the energy management footprint could be generated showing the relative headings of the nearest landing site following a de-orbit, re-entry, or landing approach.

With graphic display capability, simplified flow charts or schematics could be generated to provide the instructor with instant recall for any particular system or component.

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System internal data and overall system response displays will be supplied as the by-product of the software engineers' development and system checkout of the simulation. Refer to Section 3.3.7.7.

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3.3.5.3 Supplementary Control (IOS)

The IOS will be provided with the capability of controlling the functions normally under GSE control during the simulation of the preflight phase of the vehicle. These control functions will be presented to the instructor by a CRT so that the function is clearly understood and may be easily used.

The function of Mission Control through the Up-Link Command Subsystem will be provided to the instructor by both system function and by coded tabular entry. Provision will be made if possible to avoid having the instructor enter binary coded data for these command functions and to provide binary code insertion for coded command symbols or alpha numerics.

The IOS will be provided with special display/entry page formats so that software data pool may be accessed and modified.

3.3.5.4 Operational Instrumentation Conditioning Subsystem

The power conditioning units, transducer power supplies, and the associated power for signal conditioning of measured and display parameters will be simulated using only dynamic bilevel parameter measurements. These measurements read the nominal value or the minimum value if disabled by malfunctions entered or by loss of power to the unit.

The program will simulate conversion of DC power from the main buses to DC power at voltages required by instrumentation DC power system loads. This simulation will include power supplies such as ± 5 , ± 24 , ± 28 volt supplies and loads such as display transducers and signal conditioning equipment. All major components such as DC-DC converters, transducers, and signal conditioning equipment will be simulated using Boolean terms representing the state of circuit breakers and switches of the major components.

The program will perform the dynamic bilevel calculations of the required supply voltages and equipment operational status.

The system will also provide the computed load parameters to the power bus loading subsystem for bus conductance computations and to the ECS sub-system for heat loading. Signal conditioning of parameters for telemetry processing will be simulated by each system checking a Boolean term representing "signal conditioning equipment operational".

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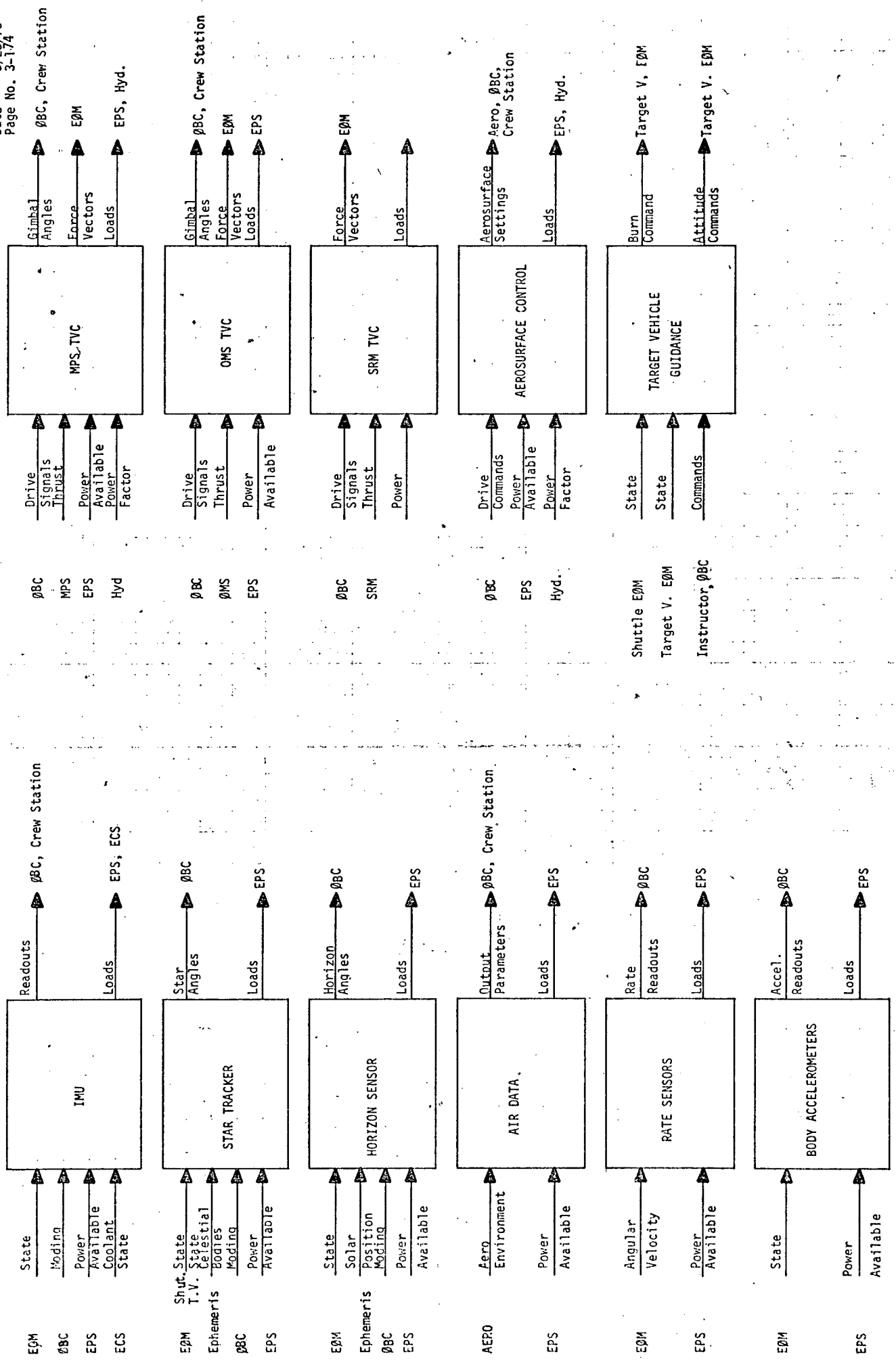
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Individual components of the DC-DC converters, transducers, and signal conditioning equipment will not be simulated. Dynamic multilevel parameter calculations will not be necessary since unit input power is not monitored. A converter ON/OFF Boolean will be used to calculate converter temperature since the heat generated by the converter is assumed to be constant when the converter is operational. The overall effect of simulation will be that the unit is either totally operational or completely inoperable.

3.3.6 Guidance, Navigation, and Control

In this section, the conceptual designs for the shuttle vehicle Guidance, Navigation, and Control (GN&C) System are presented, except for the on-board Guidance computers, flight software, and associated interface equipment. The simulation of the on-board computers and their interface equipment is discussed in the Hardware Conceptual Design document. The remainder of the Guidance, Navigation, and Control System comprises navigation and control sensors and thrust vector/aerosurface control subsystems. Sensors discussed below are the Inertial Measurement Unit, Star Tracker, Horizon Sensor, Air Data Computer, body-mounted rate sensors, and body-mounted accelerometers. Other control subsystems considered are the Main Propulsion System Thrust Vector Control, Orbital Maneuvering System Thrust Vector Control, Boost Solid Rocket Motor Thrust Vector Control, and Aerosurface Control. The conceptual design of the generalized target vehicle guidance system is also presented herein. All functions performed by on-board computer flight software are covered in the Hardware Conceptual Design. Since coupling of GN&C subsystems ordinarily takes place through the on-board computer, (e.g., IMU and Star Tracker during platform realignment) they are presented herein as essentially independent subsystems. The configuration of the GN&C simulation is illustrated below:



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3.3.6.1 IMU

The IMU simulation will simulate the operation of each of the on-board Inertial Measurement Units. The operation of each of the redundant devices will be simulated independently and simultaneously. It is not currently clear whether the shuttle will use gimballed or strapdown IMUs. A gimballed IMU used on the shuttle vehicle would be a four-gimballed, "all-attitude" device, possessing one redundant gimbal to protect against loss of inertial reference during "gimbal lock". Inputs to a simulation of a gimballed IMU will include vehicle body acceleration (not including gravity - from Translational EOM), vehicle rotational state (Rotational EOM), moding commands, gimbal and gyro torqueing commands (on-board computers), electrical power available, ECS temperature control capacity available, instructor inputs, and crew station switch and circuit breaker status. Outputs from the gimballed IMU simulation will include current gimbal angle resolver outputs, platform accelerometer outputs, power load, heat load, built-in test equipment outputs, and crew station outputs (FDAI, caution and warning, etc.). It is assumed that an IMU thermal control subsystem exists, in order to minimize temperature-related biases to achieve acceptable accuracy. If it exists, it must be functionally simulated. Heat added to the IMU by significant sources will be estimated as a function of electrical power drawn by those sources. Effects of surrounding gas temperature will be included. Heaters, if they exist, will also be simulated in this fashion. Heat transferred to coolant will be calculated as a function of IMU temperature, coolant state and blower state. Thermostatic control of heaters and blowers will be simulated. Power loads due to heater or blower operation will be

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provided to the simulated Electrical Power System. IMU temperature will be calculated from heat added to the IMU and heat transferred to the coolant. All IMU operational modes will be simulated, including modes in which the platform stabilization loops are opened. When in cage mode, the platform angles will be returned to null and maintained there. Gimbal torqueing commands (if the capability exists) and power failure effects will be simulated, and the resulting platform orientation with respect to inertial space maintained. When the stabilization loops are closed (normal operation), gyro drifts will be calculated and propagated through the simulation. Drift sources will include free bias and random drift, acceleration sensitive (mass unbalance) drift, and acceleration-squared sensitive (anisoelastic) drift. Dependence of drift properties upon gyro temperatures will be simulated. Acceleration components in gyro input, spin, and output axes will be obtained from the accelerometer simulation in platform axes, and be conditioned by a matrix representing gyro misalignments. Drift properties will be supplied using random numbers, and will exhibit proper standard deviation and autocorrelation when appropriate. The instructor will be given the ability to vary statistical properties, or override randomly varying parameters with constants, for each gyro. Carouselling effects will be included if appropriate. Gyro displacements due to gyro torqueing will be calculated as functions of command and current scale factor (including temperature dependence and other dispersions). Previous spacecraft training simulations have ignored the dynamics of IMU stabilization loops. This has been safe because, at most attitudes, stab loop dynamics were not significantly noticeable to the crew or computer in the three-gimballed platforms used. In the situations wherein stab loop dynamics become noticeable in such platforms, at very high middle gimbal

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angles, accurate simulation has been unnecessary. On the Apollo CSM IMU, for example, the stab loops were opened at a middle gimbal angle of 85° . A four-gimballed IMU does not have the same "gimbal lock" problem as the three-gimballed device, but the real-world stab loops do tend to demonstrate interesting (and undesirable) dynamics when the non-redundant middle gimbal angle is at or near 90° , effects called "gimbal flip." Incidentally, with the proper time history of rates, it is possible to obtain "gimbal lock" type effects on a four-gimballed platform, when, for instance, the redundant inner gimbal hits hard stops. It could happen. The exact effects of "gimbal flip" are dependent on such parameters as amplifier gains, motor torques, etc., and can be ameliorated by judicious choices thereof. Moreover, it may be possible during IMU design to find an axis (and stable member alignment) along which vehicle attitude is unlikely to remain long in a 90° offset condition, especially during critical periods. Thus, the "gimbal flip" effects may be fairly unlikely to occur. Balanced against this is the fact that stab loop dynamics are notoriously difficult to simulate in real-time due to high loop gains and, during "gimbal flip," very fast changing trigonometric cross-coupling effects. Sampled-data methods can help, but the problem is a sticky one nevertheless. It is herein assumed that by amplifier adjustment and judicious axis/alignment choice, the "gimbal flip" problem can be reduced well below the point at which simulation thereof is justified for training simulation. Thus, stab loop dynamics are ignored. This conclusion should be reviewed at a later stage in shuttle design. Hence, the transformation matrix from inertial coordinates to the true platform will be calculated directly from the gyro drifts, gyro torqueing angles, carouselling (if any), and the previous value of the matrix. Perfect stab loops are then assumed. The direction cosine matrix from rotational EOM will then be used to obtain the body to platform matrix, from which gimbal angles (properly

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quantized) and FDAI drive signals will be obtained. The platform mounted accelerometers will be simulated as operational when power is available and breakers are properly configured. Body accelerations from Translational EOM will be transformed to true platform coordinates (including carouselling, if appropriate). Accelerometer errors modeled will include bias and noise, scale factor error, misalignment, and scale factor non-linearity. Off-nominal temperature effects will be included as appropriate. Correct statistical properties will be exhibited. Instructor control over the accelerometer error model will be similar to his control over the gyro error model. Sensed acceleration will then be quantized for transfer to the on-board computer. If a non-destruct readout, or a destruct readout which nevertheless carries over fractional parts of quanta is used, this feature will be simulated. The conceptual design of the simulation of each gimbaled IMU is sketched in Figure 3.3.6.1-1.

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Symbol Dictionary for Figure 3.3.6.1-1

\vec{a}_b	Shuttle body acceleration (without gravity)
\vec{a}_{bp}	Shuttle body acceleration in platform coordinates
$\vec{a}_{IMU acc}$	IMU actual sensed acceleration
\vec{e}_{drift}	IMU gyro drift
\vec{e}_{torque}	IMU gyro torqueing angles
$[M]_{plat}$	True platform to inertial transformation
P_{IMU}	IMU power load
P_{IMUT}	IMU temperature control power load
q_{IMUT}	IMU heat lost to coolant
$[\gamma]$	Shuttle attitude direction cosines
$[\gamma]_{plat}$	Platform to body transformation
$\Delta \vec{a}_{acerr}$	Accelerometer error vector
$[\theta]_{plat}$	Indicated gimbal angles
$\vec{\omega}$	Shuttle angular velocity

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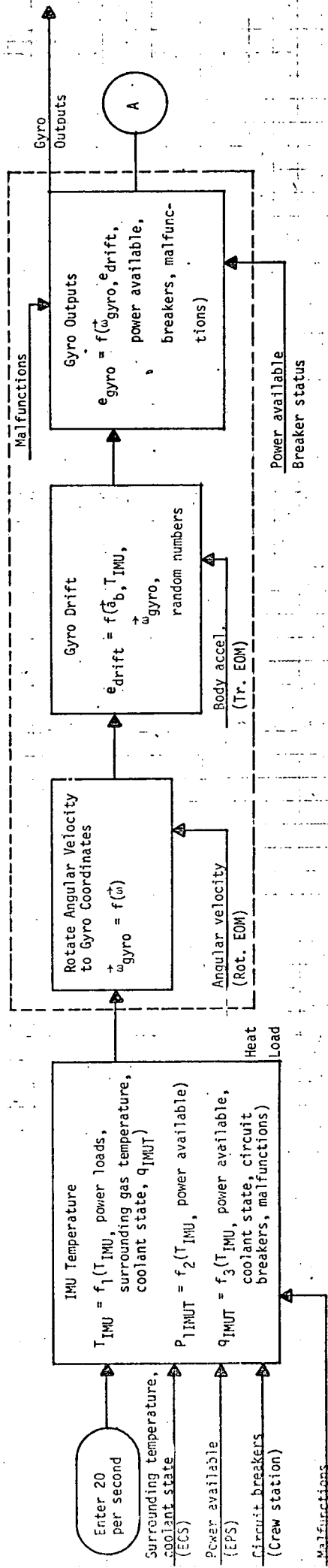
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A strapdown IMU is a device using gyros and accelerometers rigidly connected to the vehicle. The use of redundant triad or dodecahedron instrumentation arrays, mechanization of failure detection, and location of data processing are not clearly defined. A conceptual design of the sensor portion of the strapdown IMU is described in the following sentences, with the assumption that failure detection and measurement processing is handled by the on-board guidance computers. This assumption may be invalid. Inputs to the simulated strapdown IMU will include vehicle body acceleration (not including gravity - from translational EOM), vehicle angular rates (Rotational EOM), electrical power available, ECS temperature control capacity available, instructor inputs, and crew station switch and circuit breaker status. Outputs from the strapdown IMU simulation will include current gyro and accelerometer readouts, power load, heat load, and crew station outputs (caution and warning, etc.). A temperature control system will be simulated, if it exists, in a similar fashion to that described for the gimballed IMU. Current vehicle angular velocity is obtained, and its components in each gyro axis system (input, spin, output) are found. All drift error sources listed for gimballed platform gyros will be included, as well as rate-dependent scale factor errors and rate-squared-dependent scale factor non-linearities. Temperature dependence will be modelled as appropriate. Statistical properties and instructor intervention will be provided as described in the gimballed IMU conceptual design. Resulting gyro outputs, obtained from angular velocity in sensor axes and gyro drift, will be quantized correctly for transmission to the on-board computers. Body accelerations will be rotated to accelerometer coordinates for each device, and the accelerometer error model discussed under gimballed IMU's applied. Sensed accelerations will be quantized correctly for the use of the on-board computers. The strapdown IMU conceptual design is sketched in Figure 3.3.6.1.-2.

PERFORM FOR EACH GYRO



PERFORM FOR EACH ACCELEROMETER

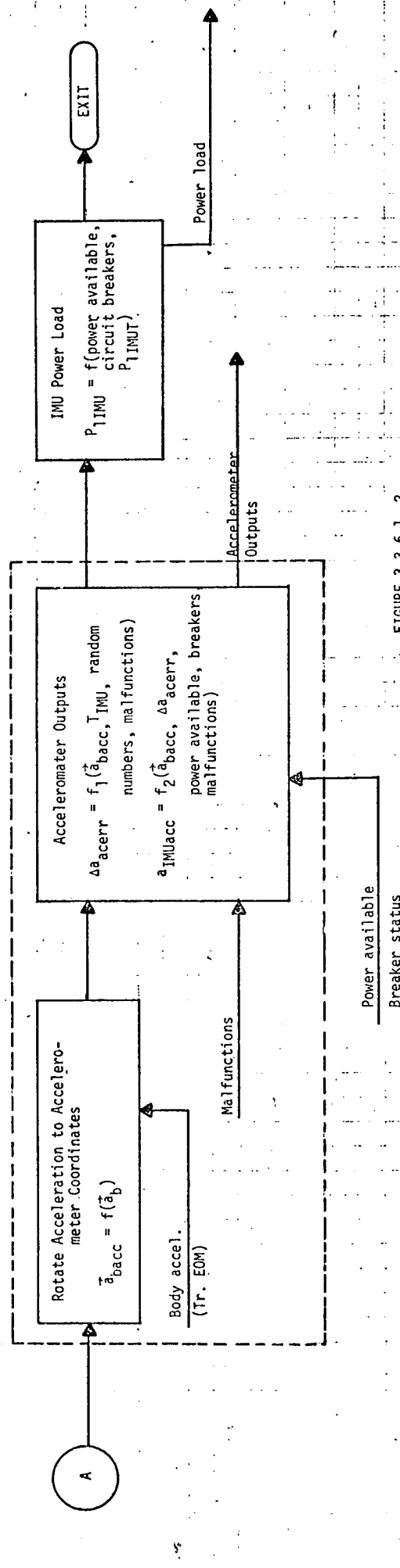


FIGURE 3.3.6.1.-2

Symbol Dictionary for Figure 3.3.6.1.-2.

\vec{a}_b	Shuttle body acceleration (without gravity)	q_{IMUT}	IMU heat lost to coolant
\vec{a}_{bacc}	Shuttle body acceleration in accelerometer coordinates	Δa_{acerr}	Accelerometer error
a_{IMUacc}	Actual acceleration sensed by accelerometer	θ_{gyro}	Gyro output
e_{drift}	gyro drift	$\vec{\omega}$	Shuttle angular velocity
P_{IMU}	IMU power load	$\vec{\omega}_{gyro}$	Shuttle angular velocity in gyro coordinates
P_{IMUT}	IMU temperature control power load		

Iteration rates of 20 per second are cited for the IMU simulation.

These rates correspond to the rotational EOM update rate. On-board computer update rates could force an alteration in IMU iteration, or, alternately, render advisable a high speed, simplified approximation loop which would be corrected at a lower frequency by the more-detailed simulation outlined above. If time is short, the accelerometer readout loop could probably be iterated at a lower rate, perhaps 10 per second.

3.3.6.2 Star Tracker

The Star Tracker simulation will simulate the operation of each of the shuttle vehicle star trackers. The operation of each of the redundant devices will be simulated independently and simultaneously. Detailed design data is not abundant on the device to be used, so a number of assumptions have been made below. Inputs to the star tracker simulation will include star tracker moding commands

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(on-board computer), shuttle body attitude (rotational EOM), celestial body positions (ephemeris), vehicle inertial position (translational EOM), power available (EPS), and crew station switch/circuit breaker settings. Outputs will include azimuth and elevation of star or beacon being tracked, device power load, built-in test equipment outputs, and crew station outputs (caution and warning, etc.). It is assumed that the star tracker possesses two basic operational modes, search and track. In search mode, the brightest light source within a small portion of the device field of view centered about a point commanded by the on-board computer will be acquired. If no light source of sufficient magnitude exists in that region, the entire field of view will be scanned and the brightest object acquired. Upon acquisition, the star tracker switches to tracking mode, and tracks the acquired light source, within a very small portion of the field of view. It is also assumed that the computer can place the device in an inactive mode. When a tracker is active, the transformation between tracker boresight coordinates and the inertial reference coordinate system is calculated. Positions of earth, sun, and moon are found in the sensor coordinate system. It is assumed that the presence of the sun, illuminated moon, or illuminated earth in or near the tracker search or track field of view will cause interference. It is further assumed the tracker can detect this interference and will send an error discrete when it occurs. When the entire field of view is occulted by a darkened earth, it is assumed that the tracker will revert to and remain in search mode. If the tracker demonstrates different behavior in those situations, it will be approximately simulated instead. It should be noted that the proposed on-board computer software has logic which will prevent any of these error conditions from occurring except in extreme IMU or computer malfunction cases. Thus, precise

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simulation thereof should not be necessary. The tracker should not work normally in case of such severe malfunction, however, so the condition must be detected and its effects approximated. In search mode, a table of star positions and magnitudes will be used to determine which stars are within the field of view. Planets in the field of view will be determined using ephemeris data. Visible target vehicle tracker beacons within the field of view will be noted, using relative position information obtained from shuttle vehicle and target vehicle translational EOM. Target vehicle tracker beacons will be activated by reset terms or instructor input. The brightest object within the applicable portion of the field of view will then be selected. Provision will be made to avoid selecting an occulted object. Brightness of stars and planets will be obtained from reset constants, while target vehicle beacon brightness will be calculated as a function of range. If no object of sufficient brightness is found within the restricted search portion of the field of view, a search of the entire field of view will be similarly simulated. When (and if) a light source is acquired, track mode will be entered. If necessary, entry into track mode will be delayed to simulate finite device search scan time (estimated at 1 second for a search of the total field of view). While the device remains in track mode, the light source will be tracked until it leaves the star tracker field of view, becomes occulted, or enters the interference region of sun, moon, or illuminated earth. If, while tracking a target vehicle beacon, another celestial object which is a more brilliant light source enters the approximate tracking view field, the star tracker will instead continue to track the celestial body. If the tracked object is still being tracked, its azimuth and elevation angle are calculated. Stellar positions used for these calculations will include the effect of aberration.

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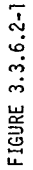
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The position will be obtained in boresight coordinates, from which azimuth and elevation will be calculated, including the effects of sensor misalignment, tracker noise error as a function of apparent magnitude, and scale factor error. Instructor control over statistical properties in the error model will be provided. Output values will be quantized as appropriate. Since the on-board computer contains calculations to ensure that no star is tracked whose apparent direction is that of the earth, refraction due to earth atmospheric effects is not a problem in nominal or near-nominal operation. It could be significant in severe malfunction cases, however. Thus, a simple refraction model will be used on directions of stars whose light passes through a significant level of the earth atmosphere, in order to assure the existence of some dispersion in this case. There is currently no data available on influence of temperature upon device dispersions or the existence of a device temperature control subsystem. Thus, such effects have been omitted. This may have to be altered as further data becomes available. It appears that the on-board computer may interrogate the star tracker angles at any time. Presumably, during star tracker use, body rates would be small--on the order of a 0.1 degree/second. Hence, in 50 milliseconds, motion of 36 arc-seconds could occur. Anticipated star tracker resolution is 30 arc-seconds. As the IMU is updated each 50 milliseconds, it appears that, to obtain reasonable realignment measurement simulation, the star tracker angles must be updated at the same rate. If time is critical, sufficient accuracy could probably be obtained by extrapolation by integrating using body rates directly, and updating at slower intervals with the full program. At this time, however, a 50 millisecond update time is used. The conceptual design for a star tracker is sketched in Figure 3.3.6.2.-1.



Symbol Dictionary for Figure 3.3.6.2-1.

h	Shuttle altitude
$[M]_{ST}$	Inertial to sensor coordinate transformation
P_{lst}	Star tracker power load
\vec{r}	Shuttle vehicle position vector
\vec{r}_{TV}	Target vehicle position vector
\vec{U}_{brite}	Direction of brightest object
\vec{U}_{est}	Earth direction, sensor coordinates
\vec{U}_m	Moon direction, inertial coordinates
\vec{U}_{mst}	Moon position, sensor coordinates
$\vec{U}_{Planets}$	Planetary positions, inertial coordinates
\vec{U}_s	Sun direction, inertial coordinates
\vec{U}_{sc}	Center of search area
\vec{U}_{sst}	Sun direction, inertial coordinates
\vec{U}_{trck}	position of object being tracked, sensor coordinates
V_{ces}	Aberration parameter
$[\gamma]$	Shuttle vehicle attitude direction cosines

3.3.6.3 Horizon Sensor

The horizon sensor simulation will simulate the operation of each of the on-board horizon sensors. The operation of each of the redundant devices will be simulated independently and simultaneously. Detailed design data is not abundant on the device to be used, so a number of assumptions have been made below. Inputs to the horizon sensor simulation will include vehicle position (translational EOM), solar position (ephemeris), vehicle attitude (rotational EOM), power available, and crew station switches and breaker settings. Outputs will include the angular reading from each sensor head, subsystem power load, built-in test equipment outputs, and crew station outputs (caution and warning, etc.). It is assumed that each sensor head possesses one degree of rotational freedom, and that its angular output is equal to the displacement of the sensed horizon from a null point within that rotational plane. Or, more specifically, if s is the angular output, and \vec{U}_{horiz} is the appropriate unit vector (i.e., the vector within the sensor's field of view) which is within the plane whose normal is the sensor head's rotational axis, and is tangent to the curve formed by the intersection of that plane and the earth "horizon surface," and \vec{U}_{null} is the unit vector representing the sensor head's null point,

$$s = \arccos (\vec{U}_{\text{horiz}} \cdot \vec{U}_{\text{null}})$$

Providing that power is available and crew station switches and breakers are properly configured, the geometry of the earth-vehicle-sensor head system will be solved to obtain the vector \vec{U}_{horiz} described above. Geometrically, there will, in general, be two such vectors, only one of which is within the sensor field of view. That vector within the field of view will be the one hereafter used.

Ordinarily, the sensors will be used only when in, approximately, a local

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horizontal vehicle attitude. If the attitude is very far removed from local horizontal (and, for shuttle low altitude orbits, only in that case), there may be zero, or even two horizon crossings within the field of view. Horizon sensor response to this situation is assumed to consist of the issuance of an error discrete, and will be simulated. The horizon detected by the sensor head will probably not be the "visual" horizon, but rather an infrared horizon. The true horizon will be simulated using the Fischer ellipsoid for the earth surface model, and a constant altitude increment plus models of altitude variation as a function of latitude and month for the infrared horizon. The horizon sensor head angular output will be obtained from the position of the true horizon sensed, with the inclusion of the effects of sensor misalignment, drift, and a random noise variation accounting for signal to noise effects. Instructor control over statistical properties in the error model will be provided. Output values will be quantized as appropriate. Temperature dependent effects will be simulated as applicable. The assumed capability of the horizon sensor to sense solar presence and inhibit outputs will be simulated. Device control loop lags will be simulated if significant. Program update rate will be dependent upon device response speed and on-board computer update rate. It appears from rather uncertain data that device response may be relatively slow, so an update rate of twice per second is used. Additional design data, as it becomes available, may require a change. The conceptual design for the simulation of a horizon sensor head is sketched in Figure 3.3.6.3.-1.

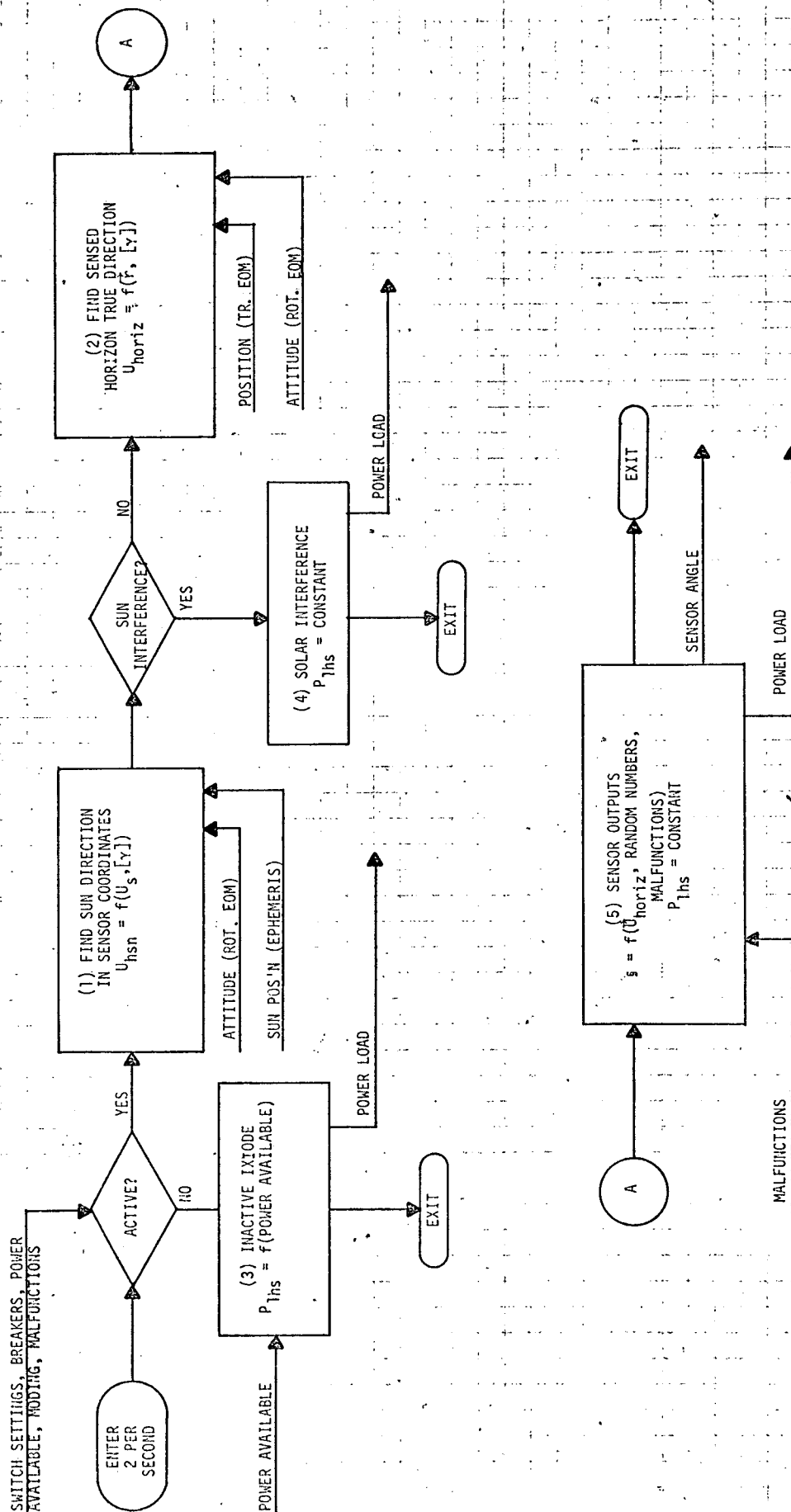


FIGURE 3.3.6.3-1

Symbol Dictionary for Figure 3.3.6.3.-1

 P_{lhs} horizon sensor power load \vec{r} shuttle vehicle position \vec{u}_{horiz} unit vector in sensible
horizon direction (sensor
viewing plane) \vec{u}_{hsn} solar position in sensor
coordinates \vec{u}_s solar position in inertial
coordinates $[\gamma]$ shuttle vehicle attitude
direction cosines s horizon sensor angular
output

3.3.6.4 Air Data Computer

The shuttle orbiter air data computer will be simulated throughout its useful altitude range. Inputs to the simulated Air Data Computer will include pressure altitude, static atmospheric pressure, dynamic pressure, and outside air temperature (shuttle aerodynamics), crew station switch and breaker settings, pilot barometric correction, power available, and instructor inputs (malfunctions, etc.). Outputs will include parameters output from the real-world device to the on-board computers and crew displays (pressure altitude, baro-corrected altitude, altitude rate, computer air speed, true air speed, mach number, total temperature, static temperature, and built-in test indicator outputs), and power load. It is assumed that certain hold functions of the DC-10 air data computer, which is assumed to typify the shuttle air data computer, will not be used, and need not be simulated. It is assumed that all control functions are performed by the on-board guidance computers. As it is not currently clear exactly what the air data is used for in the current shuttle configuration, it is hard to tell how painstakingly it must be calculated. It will apparently be used for SAS gain scheduling and crew displays. If there are no other uses, a detailed dispersion model is probably unnecessary, especially for temperatures. Requirements for simulation of digital filters are also questionable in this case. It will be assumed herein that filtering effects are not significant. If required, filters will be adjusted, if necessary, to compensate for a change in iteration rate. Pressure inputs (static and total) will be found from the inputs from shuttle aerodynamics. Noise can be added, but is probably unnecessary. Outputs which are a function of the pressure terms will then be calculated with the same equations as those used in the real-world device (pressure-altitude, baro-corrected

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altitude, altitude rate, mach, computed air-speed). Temperature dependent parameters will be calculated directly from the temperature datum from shuttle aerodynamics, as well as previously calculated air data parameters, by methods analogous to the equations used by the real-world device for an input of sensed total air temperature. As the fidelity of simulation described above rests wholly on an assortment of assumptions, further data when it becomes available may require more detail, or permit further simplification. The DC-10 air-data computer updates some terms at a rate of 16 per second (pressure-altitude, baro-corrected altitude, altitude rate), the remaining pressure dependent terms at 8 per second, and the temperature dependent terms twice per second. Most filters operate at a 16 per second rate. A 20 per second update rate is used herein for the simulated air data computer. However, if the data is used only for the purposes cited herein, and with the assumed accuracy, it would appear that a 10 per second update rate may well be sufficient. The conceptual design for the simulation of an air-data computer is sketched in Figure 3.3.6.4.-1.

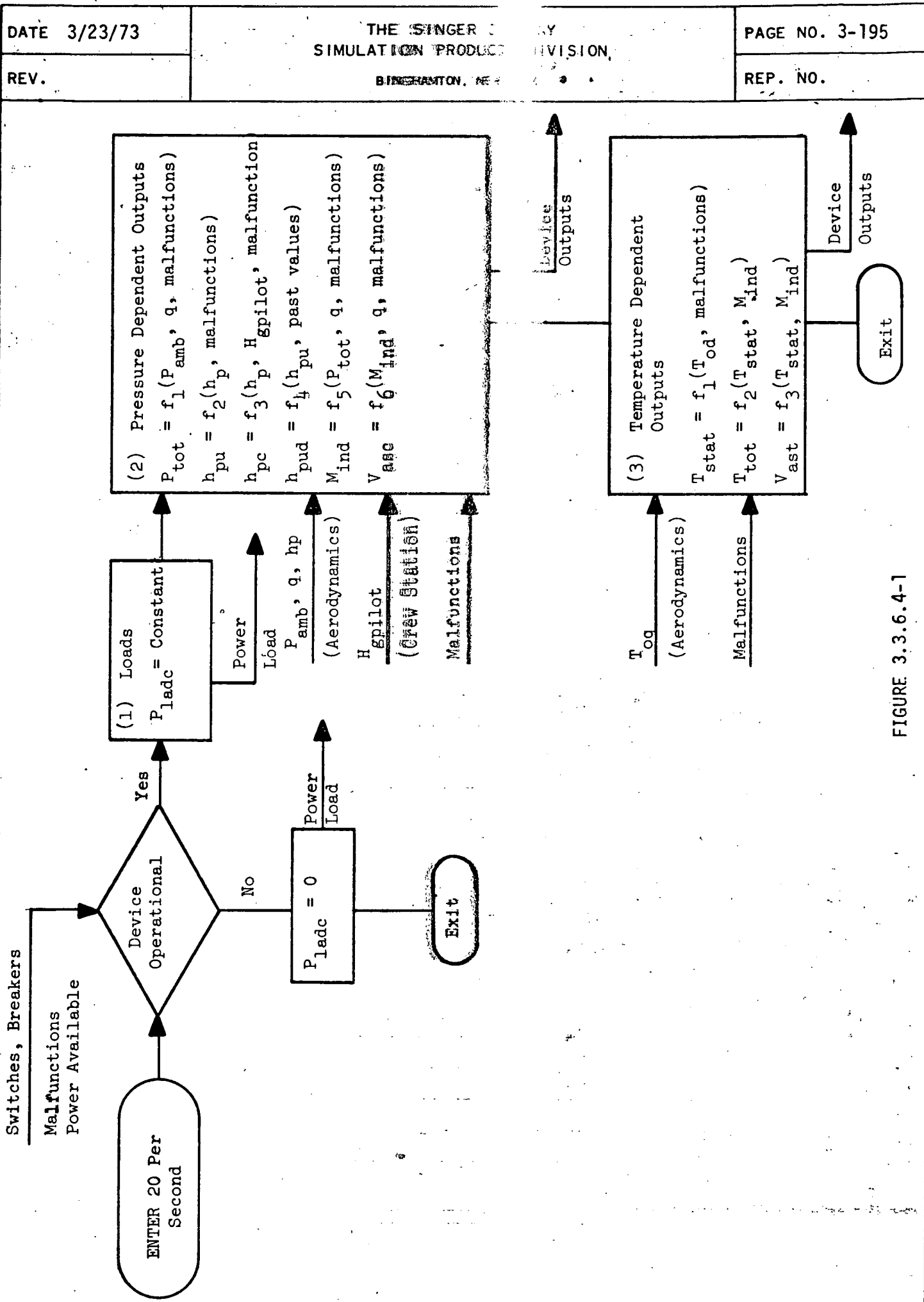


FIGURE 3.3.6.4-1

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Symbol Dictionary for Figure 3.3.6.4.-1.

H_{gpilot}	Pilot-set barometric correction
h_p	Pressure altitude
h_{pc}	Baro-corrected indicated altitude
h_{pu}	Indicated pressure altitude
h_{pud}	Indicated altitude rate
M_{ind}	Indicated mach number
P_{amb}	Ambient atmospheric pressure
P_{ladc}	Power load due to air-data computer
P_{tot}	Total sensed pressure on vehicle
q	Dynamic pressure
T_{oa}	Static air temperature
T_{stat}	Indicated static air temperature
T_{tot}	Indicated total air temperature
V_{asc}	Computed air speed
V_{ast}	Indicated true air speed

3.3.6.5 Rate Sensors

The rate sensor simulation will simulate the operation of each of the vehicle rate gyros (excepting gyros which comprise a part of the primary IMU's) which form a part of the shuttle orbiter. Each rate sensor's operation will be simulated independently and simultaneously in simulated real-time. It is assumed that, in the latest known shuttle real-world GN&C configuration, these rate sensors serve only to provide rate feedback in the vehicle control loop, similar to the Saturn body-mounted rate gyros. Thus, even 3σ drifts, scale factor errors, etc., are unlikely to have any significant effect on vehicle dynamics, since resulting false rates will be tiny compared with vehicle rates, and will not propagate in navigation. If these gyros are instead (or in addition) used in a backup strapdown navigation system, the comments pertaining to error models, etc., for gyros used in strapdown IMU's (section 3.3.6.1) will apply here as well.

Inputs to the rate gyro simulation will include vehicle angular velocity, crew station switch and breaker configuration, power availability, and instructor inputs. Outputs from each simulated rate gyro will include sensed angular velocity, power load, and thermal output. The component of angular velocity (from the rotational equations of motion) along the gyro axis will be calculated. This value will, after quantization and any other required output processing, be used as the device output, providing switches and breakers are properly configured and power is available. Since the equations of motion are updated once each 50 milliseconds, a similar update rate is specified for the body-mounted rate gyros. This interval can be increased if digital control system update is slower, and may have to be decreased if it is faster. The conceptual design of the simulation of a rate sensor is sketched in Figure 3.3.6.5.-1.

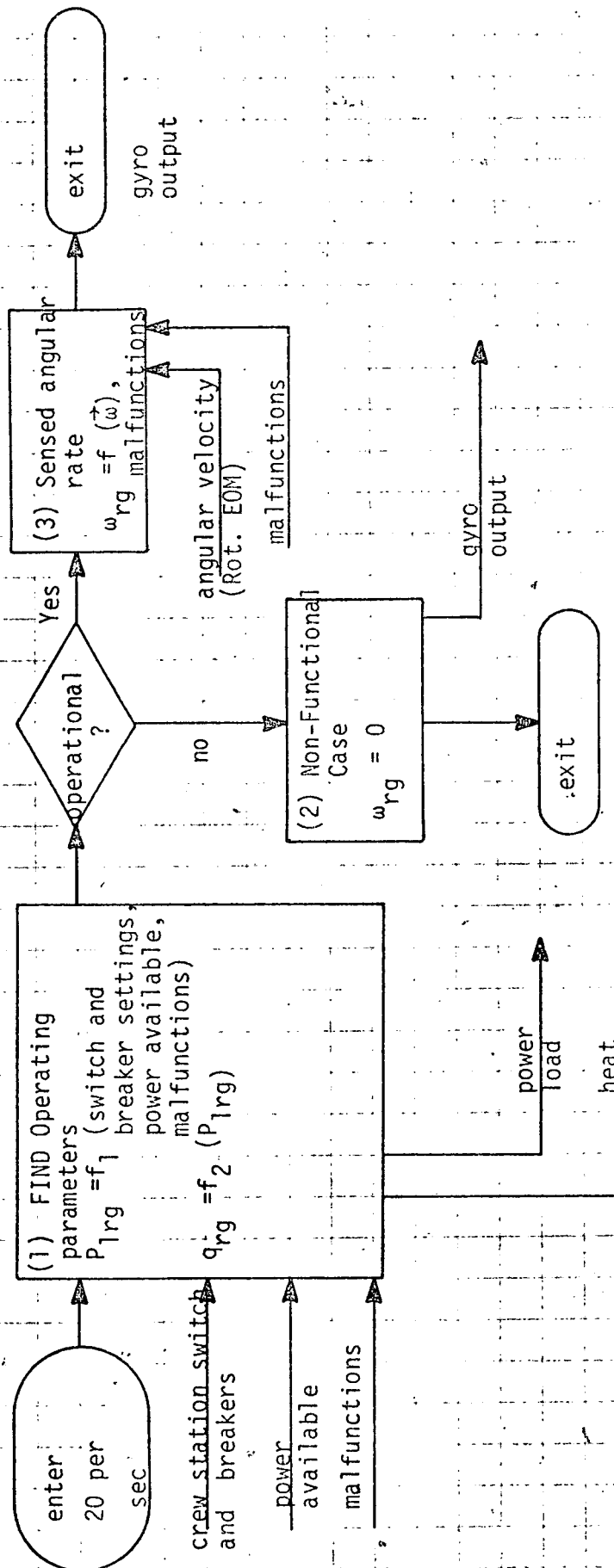


FIGURE 3.3.6.5-1

Symbol Dictionary for Figure 3.3.6.5.-1

P_{lrg}	rate gyro power load	$\vec{\omega}$	shuttle angular velocity
q_{rg}	rate gyro heat generated	ω_{rg}	body rate sensed by rate gyro

3.3.6.6 Body Accelerometers

The body-mounted accelerometers simulation will simulate the operation of each of the body-mounted accelerometers (excepting those accelerometers which comprise a part of primary Strapdown IMU's) which form a part of the shuttle orbiter. The operation of each body-mounted accelerometer will be simulated independently and simultaneously in simulated real-time. It is assumed that, in the latest shuttle real-world GN&C configuration, these accelerometers serve only to provide load relief inputs in the vehicle control loop, in a similar fashion to the Saturn 1B body-mounted accelerometers. Thus, even 3σ biases, scale factor errors, etc., will probably be sufficiently small as to have no noticeable effect on vehicle control, and will not affect vehicle navigation. If these accelerometers are instead (or in addition) used in a backup strapdown navigation system, the comments pertaining to error models, etc., for accelerometers used in Strapdown IMU's (section 3.3.6.1) will apply here as well. Inputs to the accelerometer simulation will include body accelerations, crew station switch and circuit breaker configuration, power available, and instructor inputs. Outputs from each simulated body-mounted accelerometer will include sensed acceleration, power load, and thermal output. The component of body acceleration (from translational equations of motion) along the accelerometer axis will be calculated. If the device

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is located sufficiently far from the vehicle mass center for significant accelerations to result from vehicle angular rates or accelerations, these accelerations will also be included. (This would require vehicle c.g. position, angular rate, and angular acceleration to be added as input parameters.) The resulting output value will, after quantization and any other required output processing, be used as the device output, providing switches and breakers are properly configured and power is available. Since the equations of motion are updated each 50 milliseconds, a similar update rate is specified for the simulated accelerometers. This interval can be increased if digital control system update is slower, and may have to be decreased if it is faster. The conceptual design of the simulation for a body-mounted accelerometer is sketched in Figure

3.3.6.6.-1.

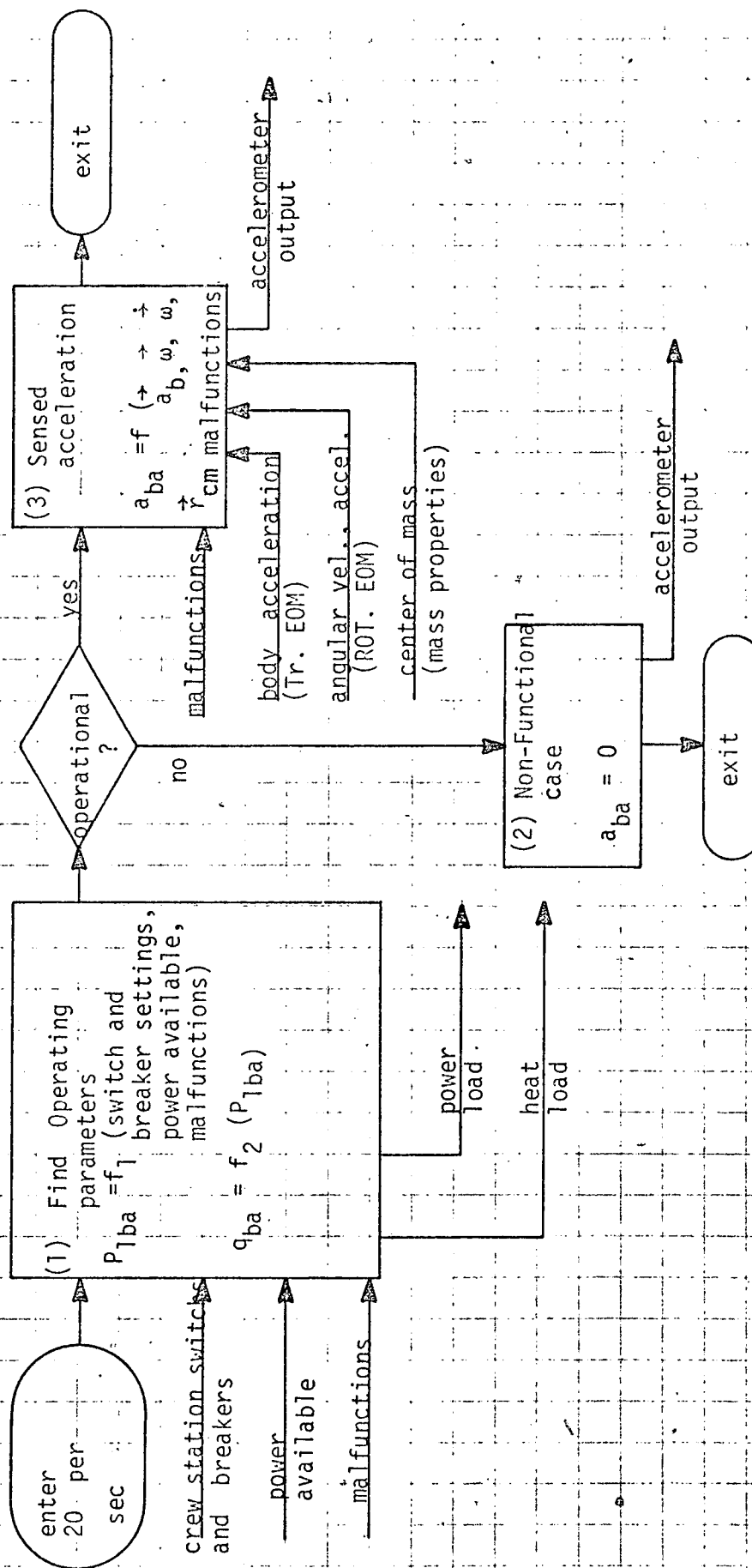


FIGURE 3.3.6.6-1

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Symbol Dictionary for Figure 3.3.6.6.-1

 \vec{a}_b shuttle body acceleration q_{ba} heat generated by body-mounted accelerometer a_{ba} acceleration sensed by body-mounted accelerometer $\vec{\omega}$ shuttle angular velocity p_{lba} body-mounted accelerometer power load $\dot{\omega}$ shuttle angular acceleration3.3.6.7 MPS Thrust Vector Control

The Thrust Vector Control system for each of the three shuttle Main Propulsion System engines will be simulated. Each of the three MPS engines TVC systems will be simulated simultaneously and independently, during the times at which the MPS TVC system is in operation. Inputs to the TVC simulation include TVC drive signals through each of the input channels (from the on-board computers), main engine thrust (from the simulated MPS), electrical power available, hydraulic power factors for each hydraulic system, crew station switch and breaker configuration, and instructor inputs. Outputs from the TVC simulation will include gimbal positions, engine force vectors (shuttle body coordinates), electrical power load, hydraulic flows, and status outputs. The MPS TVC will exhibit considerable redundancy, with multiple command signal input channels for each actuator, multiple hydraulic pressure sources for each actuator, and multiple actuators for each gimbal motion direction. Failed channels are disconnected in the case of single channel failure. Actuators are mechanized to drive to null upon certain multiple failures (e.g., loss of two of the four APU-driven hydraulic systems). The operation of the actuator redundancy management systems will be simulated and will respond properly to failures. Failure discretes, hydraulic pressure monitor

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outputs, etc., generated by the TVC drivers and monitors will be simulated and output from the TVC simulation. Actuator dynamics in each gimbal degree of freedom will be simulated as a function of input commands, failure detection status, hydraulic power factors in each hydraulic system, and malfunctions. Other effects, such as engine bell damping, will be simulated if significant. Gimbal rate and position limits, and other limits internal to the TVC, will be simulated. After gimbal positions are calculated, each engine's thrust magnitude will be resolved through the calculated gimbal angles to obtain the engine force vector. CMS SPS TVC was iterated at a 50 millisecond rate to approximate proper engine response. While further study when data becomes available may indicate that it is possible by use of sampled-data techniques to lower this rate, a similar rate is currently specified for shuttle to assure accurate closed-loop response. The conceptual design for the simulation of the TVC system for a main engine is sketched in Figure 3.3.6.7.-1.

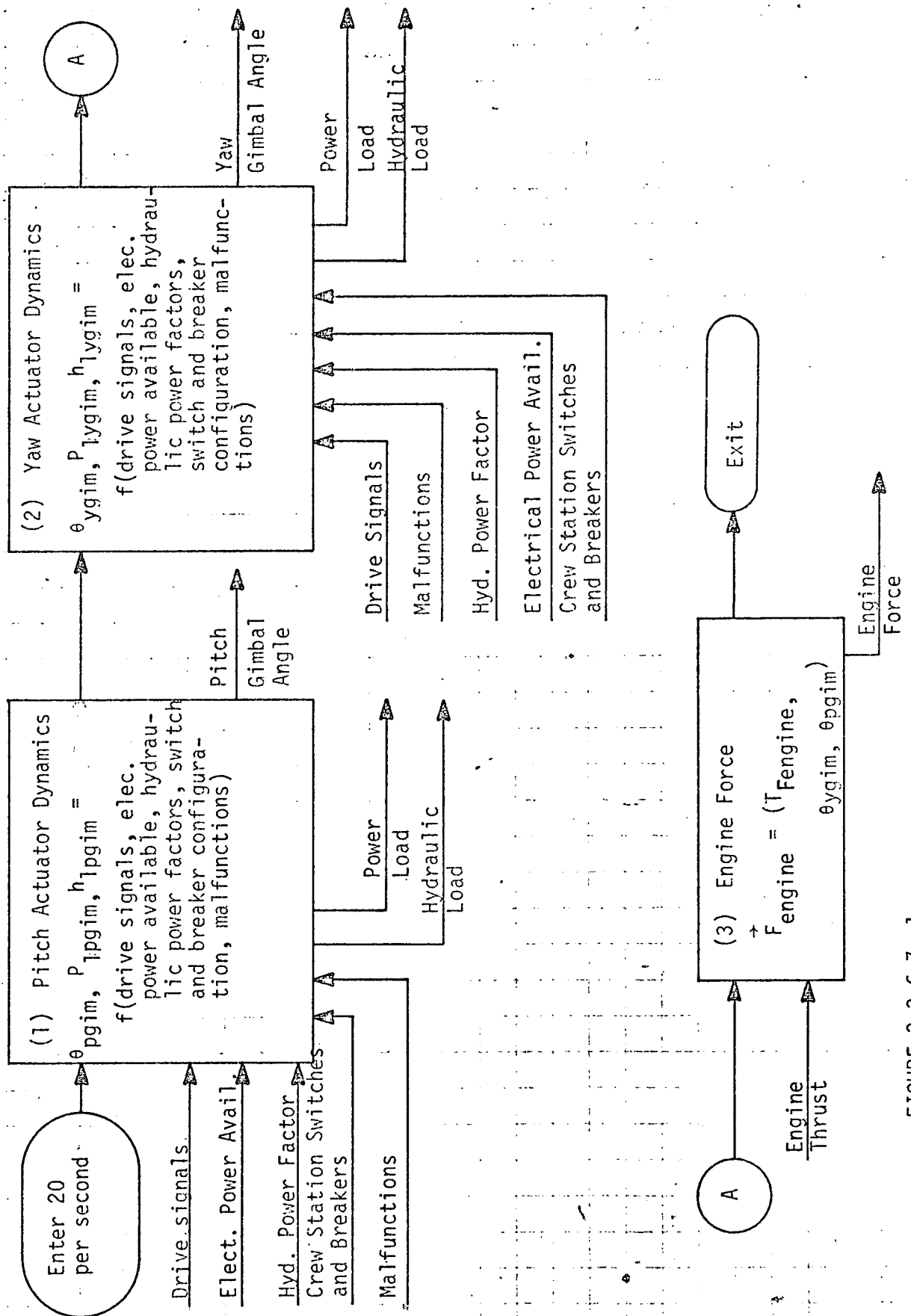


FIGURE 3.3.6.7.-1

Symbol Dictionary For Figure 3.3.6.7.-1

F_{engine}	engine force vector in shuttle body coordinates
h_{Lpgim}	pitch gimbal actuator hydraulic load
h_{Lygim}	yaw gimbal actuator hydraulic load
P_{lpgim}	pitch gimbal actuator power load
P_{lygim}	yaw gimbal actuator power load
T_{engine}	engine thrust
θ_{pgim}	engine pitch gimbal angle
θ_{ygim}	engine yaw gimbal angle

3.3.6.8 OMS Thrust Vector Control

The Thrust Vector Control system for each of the two Orbital Maneuvering system engines will be simulated. Each of the two OMS engines' TVC systems will be simulated simultaneously and independently, during the times at which the OMS TVC system is in operation. Inputs to the TVC simulation include TVC drive signals (from on-board computers), OMS engine thrust (from simulated OMS), electrical power available, crew station switch and breaker configuration, and instructor inputs. TVC simulation outputs will include gimbal positions, engine force vectors (shuttle body coordinates), electrical power loads, and status outputs. It appears that the OMS TVC is an electrical-mechanical system, with no hydraulic components, somewhat similar to the Apollo SPS TVC. The actuator dynamics of the Apollo system are significant, especially in malfunction cases. Thus, lags, overshoots, finite rise times, etc., of the actuators will be simulated. There appears to be considerable redundancy in the system, with multiple command signal

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input channels. Operation of system redundancy management will be simulated, and any resulting failure discretes will be generated.

Actuator outputs in each gimbal degree of freedom will be simulated as a function of input commands, failure detection status and malfunctions.

Gimbal rate and position limits, and other limits internal to the TVC, will be simulated. Effects such as engine bell damping will be simulated if significant. After gimbal positions are calculated, each engine's thrust magnitude will be resolved through the calculated gimbal angles to obtain the engine force vector. CMS SPS TVC was iterated at a 20 per second rate to approximate proper engine response. Further study when data becomes available may indicate that it is possible by use of sampled-data techniques to lower this rate. However, a 50 millisecond update rate is currently specified for shuttle to assure accurate closed-loop control response. The conceptual design for the simulation of the TVC system for an OMS engine is sketched in Figure 3.3.6.8.-1.

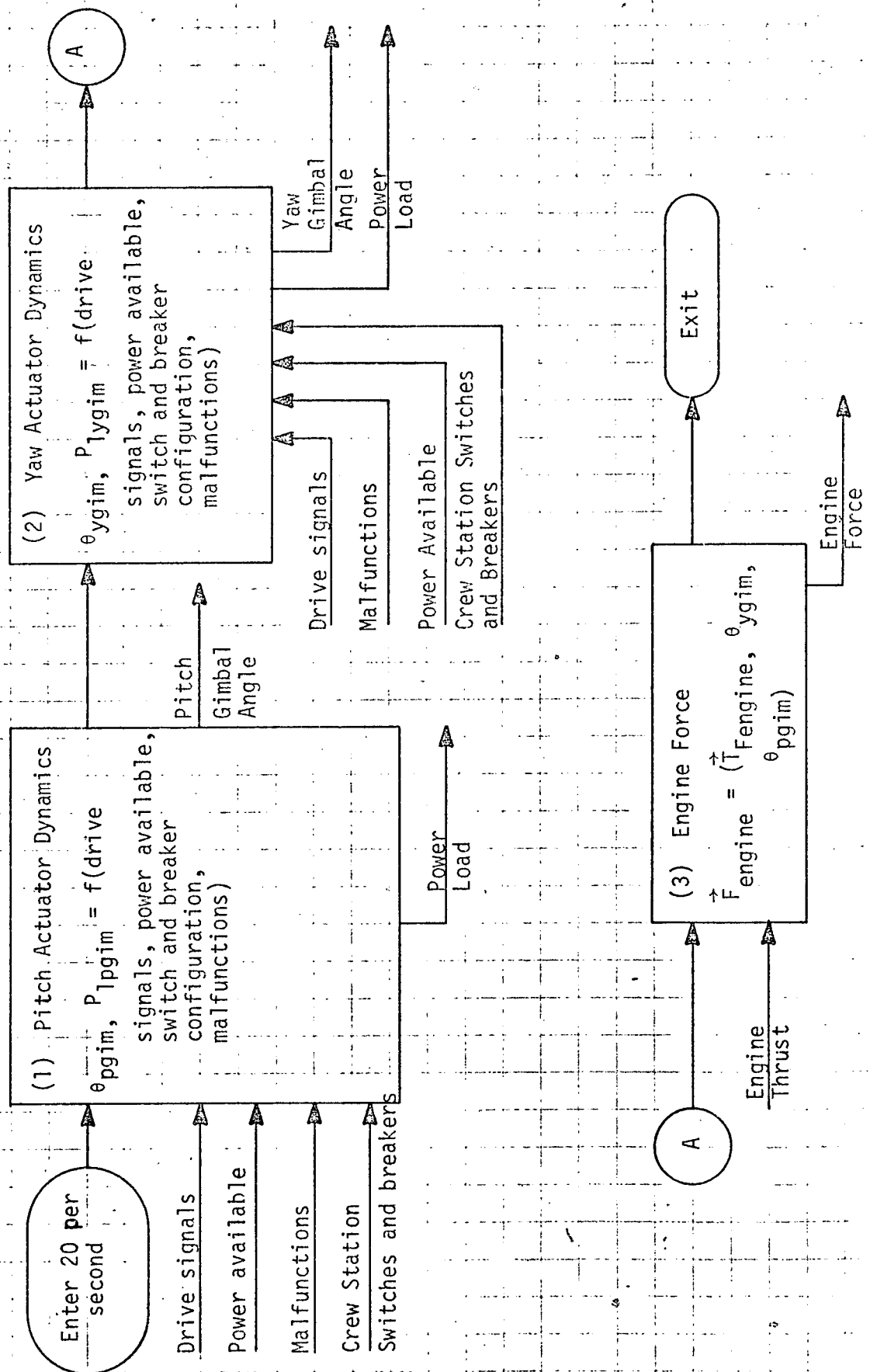


FIGURE 3.3.6.8.-1

Symbol Dictionary for Figure 3.3.6.8.-1

 F_{engine} engine force vector in shuttle body coordinates $P_{\text{lp gim}}$ pitch gimbal actuator power load $P_{\text{ly gim}}$ yaw gimbal actuator power load T_{engine} engine thrust θ_{pgim} engine pitch gimbal angle θ_{ygim} engine yaw gimbal angle3.3.6.9 Boost SRM Thrust Vector Control

The thrust vector control system for each of the two solid rocket booster engines will be simulated simultaneously and independently during the times at which the Boost SRM's are in operation. The method to be used for controlling the SRM thrust vectors is not currently known. For purposes of computer sizing, it will be assumed that the SRM TVC Simulation problem is similar to that for MPS TVC, even though it is not known if SRM engines will be gimballed, or what the power source to be used will be. Inputs to the simulation will include TVC commands and SRM thrust, and outputs will include the force vector from each SRM.

3.3.6.10 Aerosurface Control

The aerosurface control subsystem for each elevon, and the vertical stabilizer (rudder/speed brake) will be simulated. Each of the aerosurface control subsystems will be simulated simultaneously and independently when in operation. Inputs to the aerosurface control system include aerosurface setting commands through each of the input channels for elevon, rudder, and speed brake (from on-board computer), electrical

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power available (from Electrical Power Subsystem), hydraulic power factors for each hydraulic system (from Hydraulic Subsystem), crew station switch and breaker configuration, and instructor inputs. Outputs from the aerosurface control system will include elevon and differential elevon settings, rudder setting, speed brake setting, electrical power load, hydraulic flows, and status outputs. Aerosurface control will exhibit considerable redundancy, with multiple command signal input channels for the primary control servos, multiple hydraulic pressure sources for each surface hydraulic actuator, and multiple actuators for each surface. Failed channels are disconnected in the case of single channel failure. Operation of the failure detection and redundancy management provisions will be simulated and will respond properly to failures. Failure discretes, hydraulic pressure monitor outputs, etc., generated by the aerosurface control subsystem, will be simulated and output from the simulation. The summing of rudder and speed brake commands to obtain commands for the split vertical stabilizer surface will be simulated to obtain the appropriate surface hydraulic actuator inputs. Actuator dynamics for each surface will be simulated as a function of input commands, failure detection status, hydraulic power factors in each hydraulic system, and malfunctions. Other effects, such as hinge-moments, will be simulated if significant. Rate and position limits of the aerosurface, as well as other limits internal to the subsystem, will be simulated. Previous Singer experience in simulation of high L/D re-entry vehicles has indicated that an update rate of the order of 50 milliseconds for aerosurface simulation is required to maintain proper vehicle response. The conceptual design for the simulation of the aerosurface control subsystem is sketched in Figure 3.3.6.10.-1.

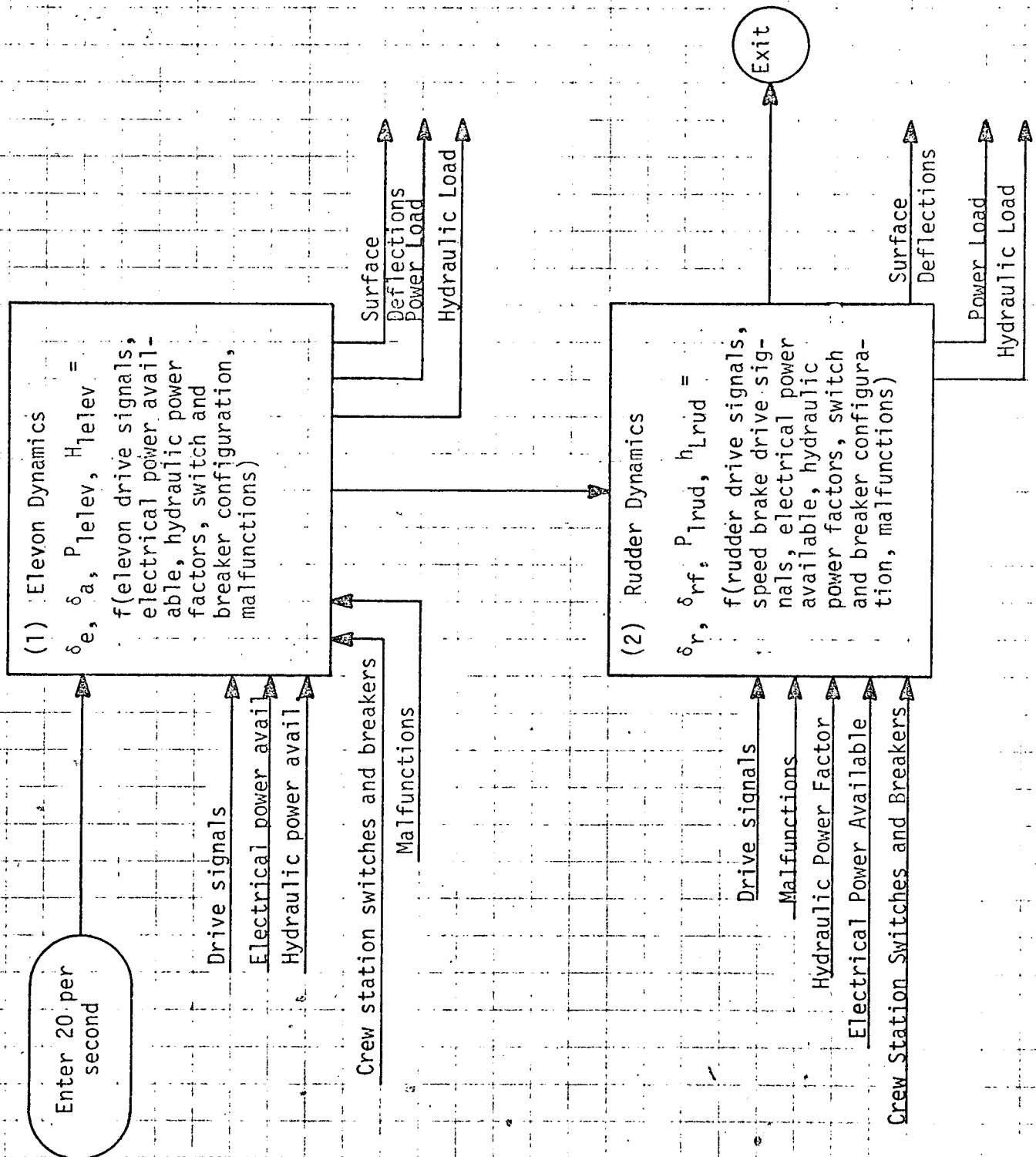


FIGURE 3.3.6.10.-1

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Symbol Dictionary for Figure 3.3.6.10.-1

h_{Lelev} elevon actuators' hydraulic load

h_{Lrud} rudder actuators' hydraulic load

P_{lelev} elevon electrical power load

P_{lrud} rudder electrical power load

δ_a ailevon (differential elevon) deflection

δ_e elevon deflection

δ_r rudder deflection

δ_{rf} rudder flare

3.3.6.11 Target Vehicle Guidance and Control

A functional target vehicle guidance system will be simulated for target vehicles. The guidance system will consist of a major loop which performs burn targetting and runs in interruptible time, and a minor loop which feeds attitude commands to the generalized target vehicle control system, and firing commands to the generalized target vehicle propulsion system. A reset boolean will be provided to bypass generalized target vehicle guidance entirely, and another provided to bypass the major loop only, for use in the case that more detailed guidance schemes for particular vehicles are added following simulator delivery. The minor loop guidance system will accept thrusting and attitude commands from either

instructor input

command from shuttle vehicle

guidance major loop/prestored commands

in that order of priority. Instructor input may take the form of direct command, or initiation of prestored commands. Shuttle vehicle commands will be honored only when a reset boolean is set indicating that this target vehicle possesses the capability to accept commands from the shuttle vehicle. Prestored commands may be used either in place of the major loop burn targetting, or merely to specify attitude following the final burn. Prestored commands will be stored as functions of time. Attitude commands (instructor/shuttle vehicle originating/prestored) may be given in terms of either inertial Euler angles or local horizontal angles, or inertial hold of a local horizontal orientation at the initial point in time. Burn targetting will be provided to the minor loop by specifying ignition time, burn duration, and inertial burn attitude (inertial

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Euler angles or inertial hold of a local horizontal orientation). The minor loop will process this information and provide inertial attitude commands for the generalized target vehicle control, and engine ignition and cutoff times to generalized target vehicle propulsion. The major loop will calculate burn targetting assuming a coelliptic rendezvous sequence of three burns (NCC, NSR, TPI). The coelliptic sequence could be expanded to later include preliminary phasing burns, if necessary. Targetting presettings will be instructor-changeable, and targetting for a given burn can be recycled by instructor command. Targetting data (ignition time, burn duration, total ΔV , attitude) will be available for instructor display. Provision will be made to inhibit TPI targetting if the shuttle vehicle will perform this burn. Burn targettings will be performed immediately following the preceding burn's conclusion, and re-performed about 10 minutes before estimated burn time. Target vehicle major loop guidance will be able to share interruptible time, and a number of (interruptible) targetting subroutines, with instructor aids targetting (described in Section 3.3.7.6). An iteration rate of 10 per second is specified for target vehicle loop guidance, matching the update rate of target vehicle rotational EOM. The conceptual design for target vehicle guidance and control is sketched in Figures 3.3.6.11.-1 and 3.3.6.11.-2.

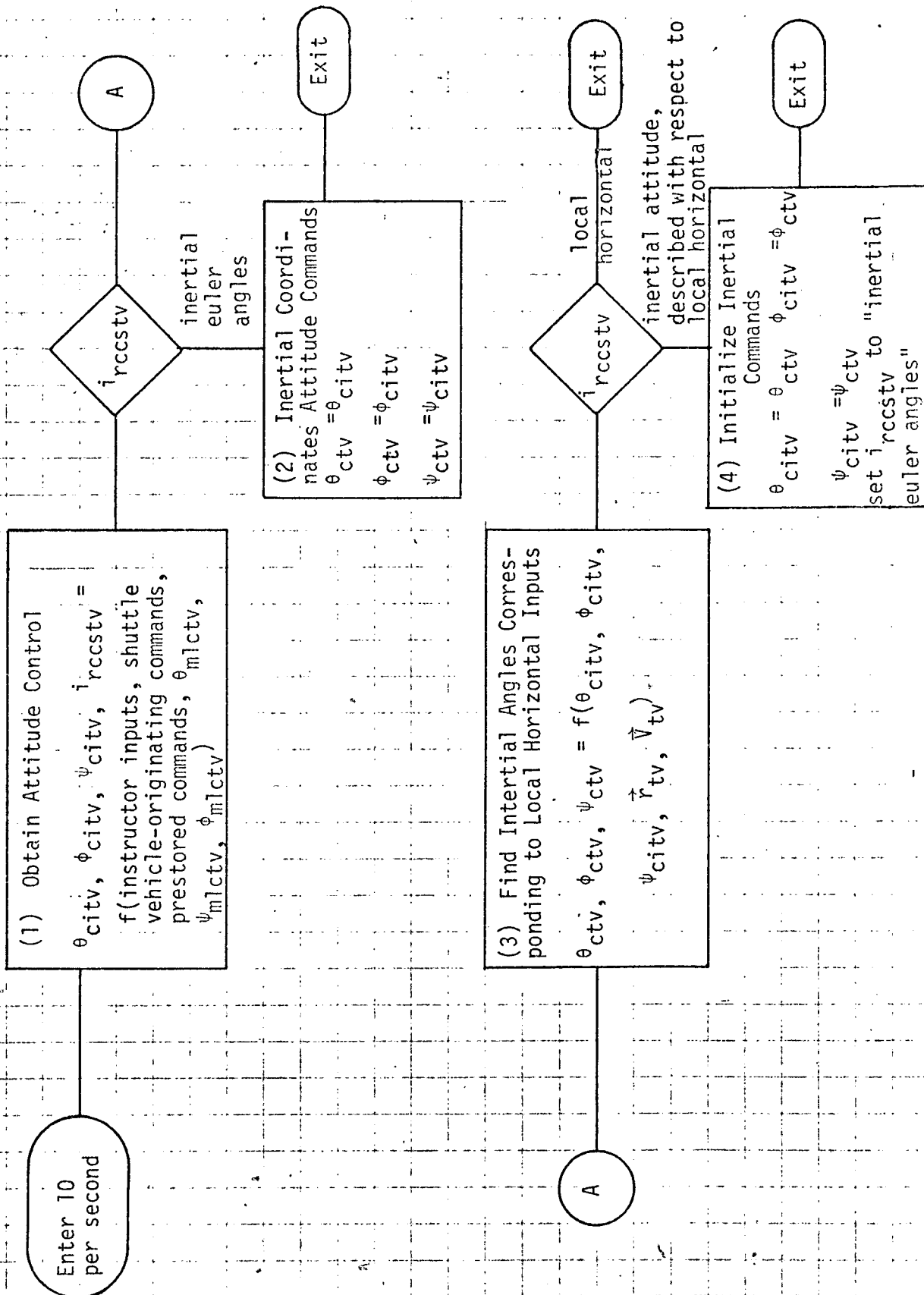


FIGURE 3.3.6.11.-1

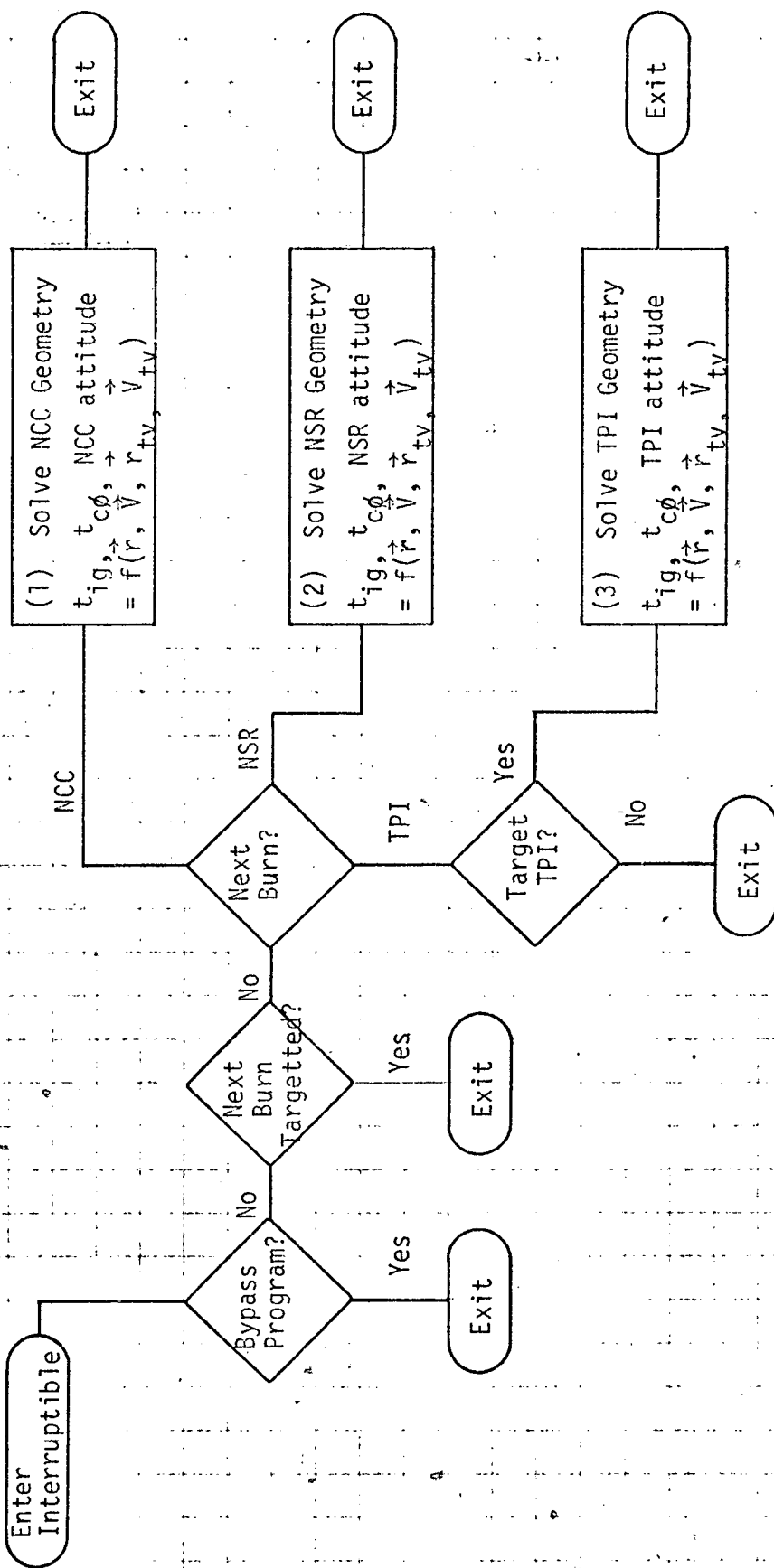


FIGURE 3.3.6.11.-2

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Symbol Dictionary for Figures 3.3.6.11-1 and 3.3.6.11.-2

i_{rcstv}	coordinate system indicator for attitude command
\vec{r}	shuttle position
\vec{r}_{tv}	target vehicle position
$t_{c\phi}$	burn cutoff time
t_{ig}	burn ignition time
\vec{V}	shuttle velocity
\vec{V}_{TV}	target vehicle velocity
θ_{ctv}	inertial pitch command to jet logic
θ_{civ}	input pitch command
ϕ_{ctv}	inertial roll command to jet logic
ϕ_{civ}	input roll command
ψ_{ctv}	inertial yaw command to jet logic
ψ_{civ}	input yaw command

3.3.7 Simulator Environment

3.3.7.1 Aural Cue

The aural simulation will consist of those audible cues which provide the crew member with vehicle operational performance characteristics during flight. Electromechanical devices are provided with appropriate software driven cues which control the audio volume, frequency, and spectrum bandwidth. Exact volume levels, frequency and spectrum bandwidth are required for each simulated device. These levels will be taken from either experimental data or calculation estimates.

The main liquid fuel rocket engine simulation will have sounds associated with burning, to include rough burn. The noise level of an engine will decrease when throttled. The engines have both fuel and oxidizer pumps which will be heard during fuel dump. There are three main engines to be simulated, each of which may be firing at a separate time. Provision will be included for simulation of multiple engines. Prior to start and post firing, metal expansion and contraction noises will be provided. Prior to reentry the main rocket engines purging will be simulated by a muted gas expansion type noise.

The two large solid rocket motors will be simulated for appropriate thrust sound and acoustic vibration. Start-up and shut-down transient noises will not be provided during normal main SRM burning. Malfunction transients will be simulated for case burnthrough. Upon thrust termination of these motors, the sound will be decreased dependent on separation distance and air density. Mechanical noises associated

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with separation should not be heard over the separation rocket noise; however, this cue will be simulated for malfunction training when the separation rockets do not fire.

The airbreathing engines' audible cues generated will include booster pump whines and explosion heard during engine start. Following start-up, a turbine whine will simulate build up to run level and continue until shut-down. During airstart, this whine will also be generated. At this time, it is assumed that the jet engines will have thrust reversal capability and the accompanying noise cue will be generated.

The external fuel-oxidizer tank simulation will create noises associated with pyrotechnic line separators, fuel and oxidizer venting prior to separation, and separation system pneumatic and mechanical thumps.

Reaction control thruster jets firing cues will be provided. The thrusters are located in the orbiter nose section and each of the aft OMS pods. The aural cue system will cause a sound on activation identifiable as to direction.

Docking sounds will be simulated for the mechanics of door opening, docking ring extension, mating, locking and the pneumatic shock absorber system. More definition is required to determine the metallic sounds to be simulated and the shock absorber pneumatic sounds.

The sounds associated with the payload area and payload deployment involve the latching and unlatching of payload doors, payload and radiator units. Hydraulic sounds will be provided for radiator

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deployment, door mechanics, and the payload manipulator. Various levels of mechanical matings will be simulated for door openings and closing, radiator deployment and retraction, manipulator mating and stowage, and payload mating with external vehicles, or return of payloads to the payload bay. Emergency jettisoning of the manipulator will be simulated by noises associated with pyrotechnic separator devices.

The simulation of the electrical system operating off the APU's and inverters will produce a 400 hertz hum. The APU will have an explosive start-up sound with a 12,000 hertz run mode background noise. There are three APU's which may be started independently.

Fuel cell venting will be simulated by pressure build up to trip limit. This sound will probably be a pop (valve opening) followed by an air hiss.

Environmental air-conditioning sounds heard when the cabin is pressurized will be valves popping - high pressure air release - and air pressurization or evacuation during EVA/IVA activity. The volume of sound will be simulated dependent upon calculated air density.

The aerodynamic control surfaces will generate a hydraulic cue when driving from one position to another. In atmosphere, an air flow noise will be generated which is a function of dynamic pressure and the amount of total surface deflection.

The aerodynamic forces will create aural cues of wind noise, turbulence, and buffeting. During reentry phases metal expansion and contraction will cause various popping and cracking sounds.

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The drag chute system will cause two minor sounds; a thump on opening of the drag chute container system and a second thump on opening of the main chute.

The landing gear system simulation will have sounds associated with the gear doors opening and closing (hydraulic cylinder activation). When the gear door begins opening, an air noise will be generated. The volume would be dependent upon air density and poor position. A mechanical thump will be generated with the gear door opening or closing. The gear deployment and retraction will create sounds associated with hydraulic motor activation. When the gear is fully extended or retracted, a mechanical thump will be generated. Noises will be generated upon operation of the breaks. Noises will also be generated from tire vibration, nose wheel shimmy, and tire contact with the runway on landing.

The audio cues of the Caution and Warning System will be simulated and triggered by software generated cues for such items as Caution, Warning, Emergency Pressure Loss, Emergency Fire, Landing Gear Not Down, and Crew Alert. These audio cues are assumed to be similar to the presently used cues for the skylab mission.

The following figure is used to graphically depict the assorted functions of Aural Cue:

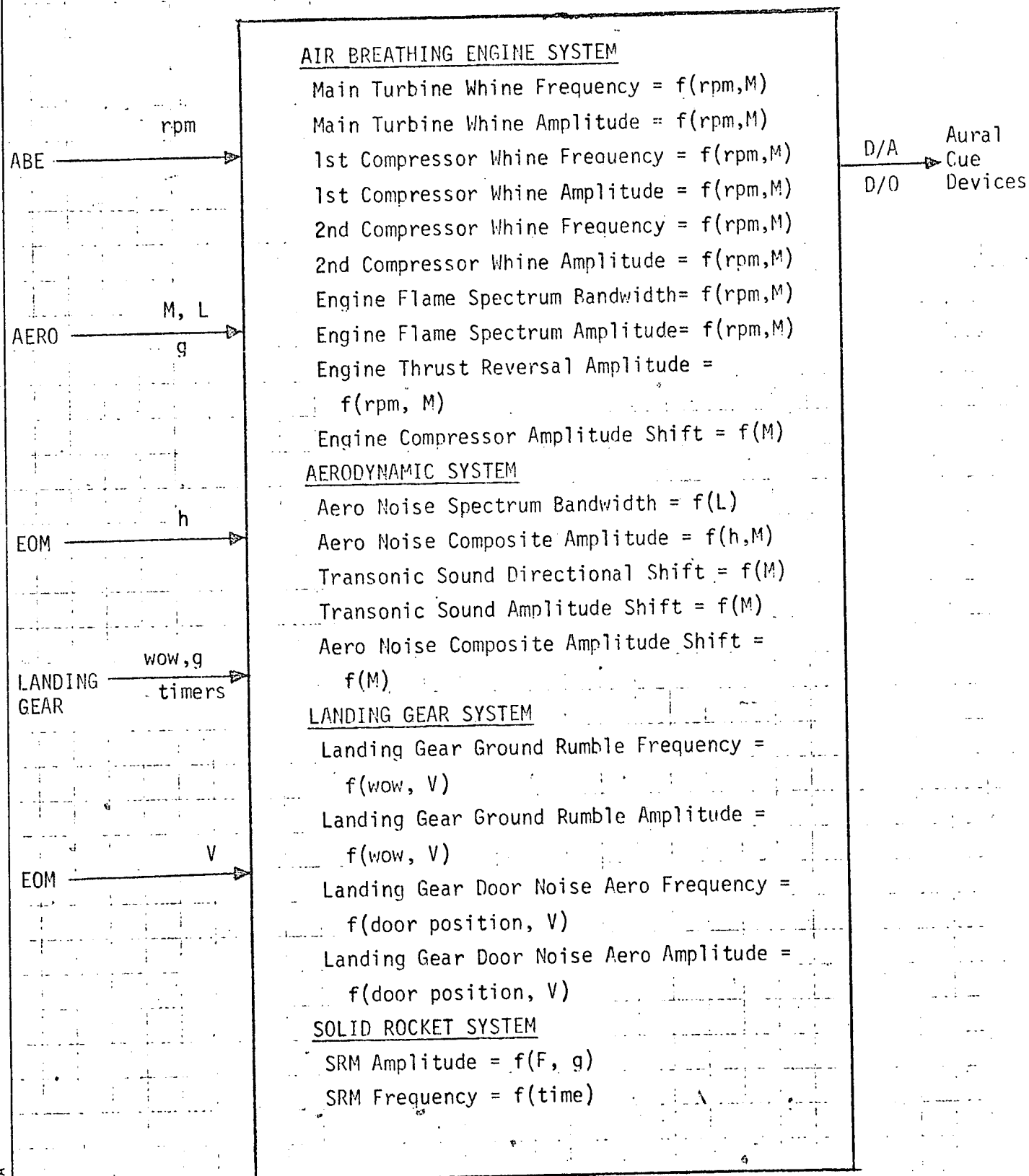
AURAL CUE
Figure 3.3.7.1-1

Figure 3.3.7.1-1(continued)

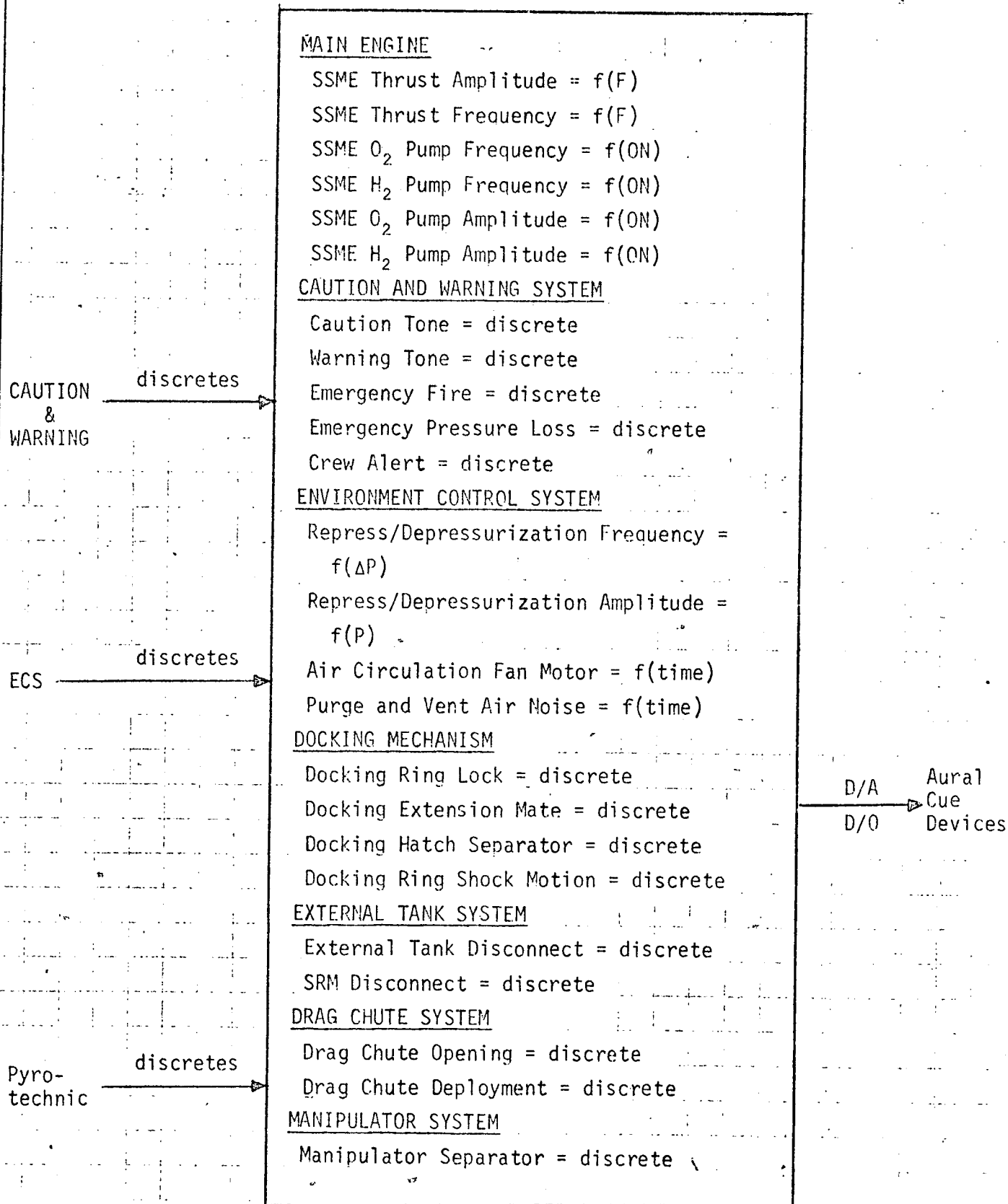
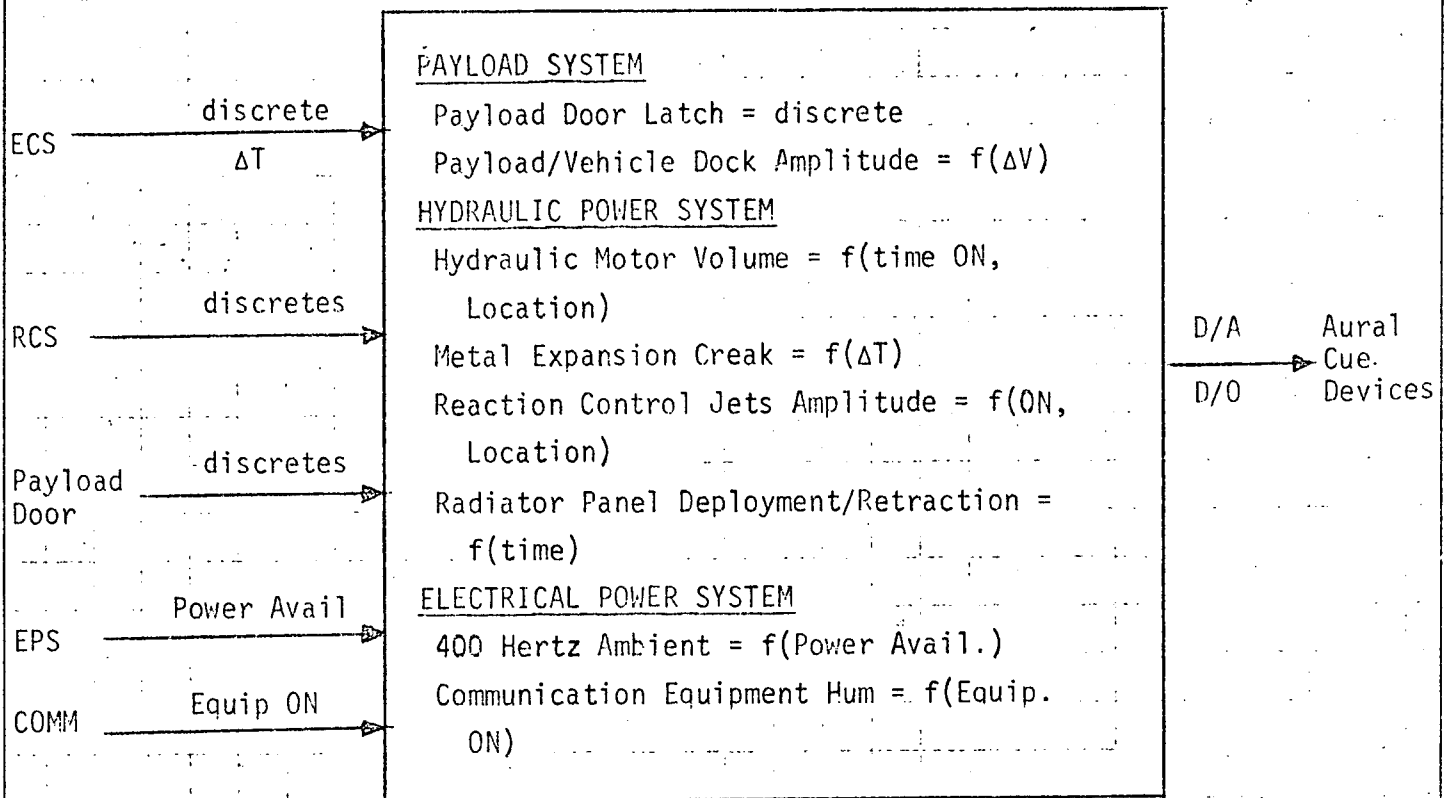


Figure 3.3.7.1-1 (continued)



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3.3.7.2 Visual (Aft)

The aft visual simulation software for the fixed base crew station will accept inputs from the simulated Equations of Motion and Payload Accommodation Systems and generate driving commands for the aft visual system. The control software configuration is highly dependent upon the final aft visual hardware design selected.

3.3.7.3 Visual (Forward)

The forward visual simulation software will accept inputs from the simulated Equations of Motion, and generate driving commands for the forward visual system. The control software configuration is highly dependent upon the final forward visual hardware design selected.

3.3.7.4 Motion System

The software package described assumes a hardware configuration of a six degree-of-freedom motion system with the addition of a simulator crew station tilt capable of 0 to +77 degrees angle and a rate of (TBD) degrees/second. Additional crew station deflection beyond 77° can be obtained from the standard 6 DOF system. The drive philosophy considered is to program the motion system to, as realistically as possible, approximate the forces acting on the crew during actual flight. The standard 6 DOF system is capable of providing all motion cues except for long-term sustained accelerations. These accelerations occur primarily along the vehicle X axis (A_x). The hardware/software system accomplishes the long-term accelerations by directing the actual gravity force to correspond to the total sustained acceleration acting on the crew for the simulated condition. Since, in orbital flight, the gravity force is effectively cancelled by centrifugal force, a "natural" upright seating position is assumed for zero force, while a deflection of 90° is assumed for maximum force during accelerated flight. A design goal for the shuttle program is to limit the total acceleration to 3 G. Therefore, the simulator is scaled to adequately cover this range, plus an off-nominal additional acceleration. A total of 3.1 G is chosen for 90° deflection of the system for long-term accelerations. An additional requirement for all axes of the motion system is felt to be an ability to adjust scaling easily. This is because the chosen scaling will probably require adjustment based on user experience with the simulator.

Scaling and rate characteristics of the design motion system should be able to handle all longitudinal accelerations and rates of acceleration change during a shuttle mission except the rate of acceleration change at main engine

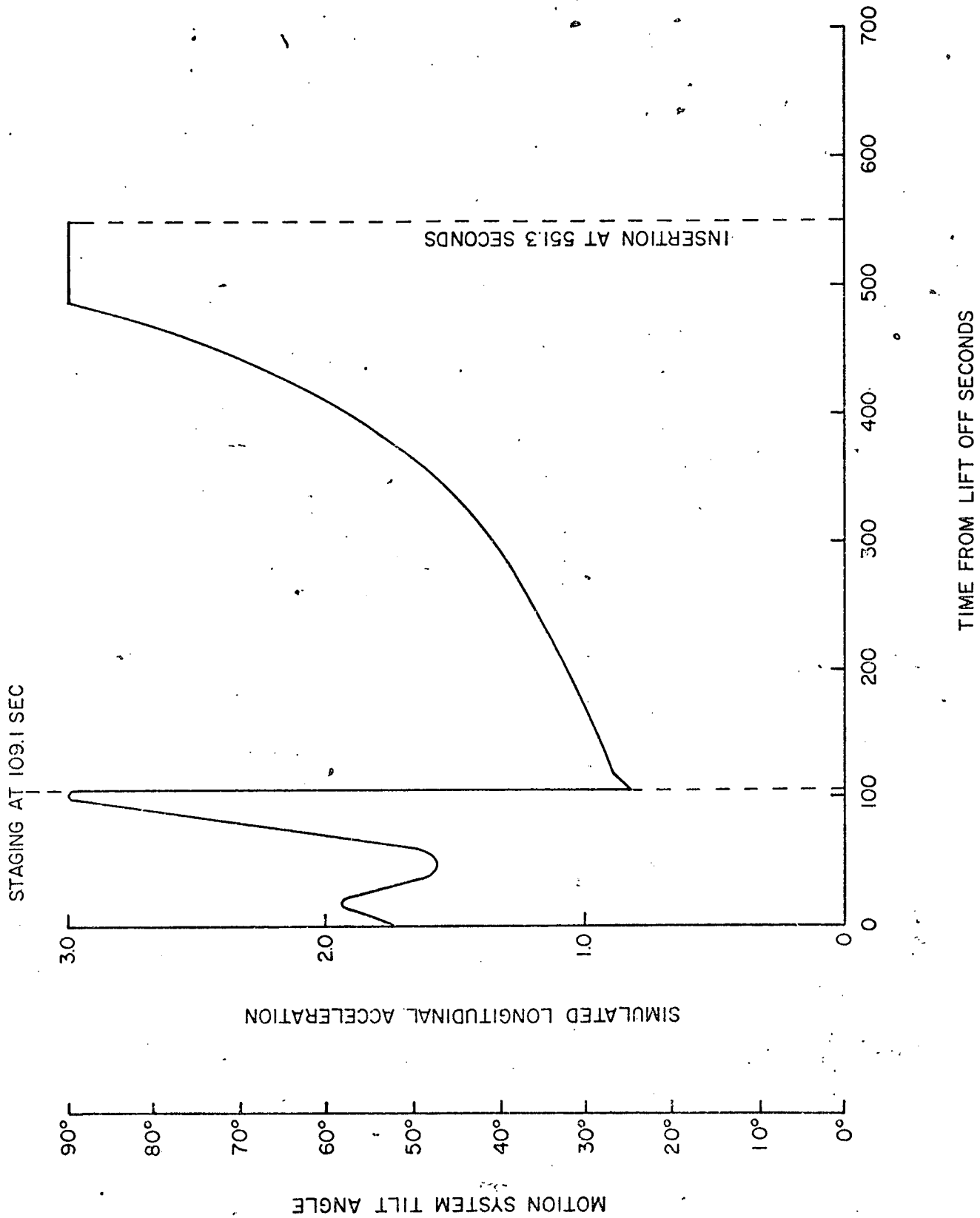


FIGURE 3.3.7.4-1

TIPT vs. ACCELERATION

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cutoff upon orbit insertion, and upon thrust termination for certain aborts. The accompanying figure illustrates nominal boost accelerations. At main engine cutoff, maximum acceleration decay is about 7.5 g/second, proportional to about 200 degrees/second at motion base scaling. A 200 degree/second rate will obviously cause hardware problems in implementation. Such a rate would also briefly result in false motion cues. The actual cue is a rather sudden cessation of great force driving the astronaut back into his couch. The 200 degrees/second motion base motion will introduce false rotational cues. However, all these cues exist for such a short period of time that they should not be too alarming. Moreover, relatively subtle differences are difficult to note when engaged in a very sizable motion cue such as cutoff. A substantially slower rate would ease hardware difficulties, and false rotational cues. It would, however, make simulated tailoff motion cues last much longer than the real-world motion cues do. Thus, it, too, would create a false cue. The short duration false cue is considered preferable to a long duration false cue. Thus, it is desirable to drive out the tilt at the largest possible maximum rate at main engine cutoff, or aborts which exhibit similar real-world cues.

The standard Singer 6 DOF motion system software is capable of accurate simulation of all motion cues except those requiring use of the added tilt feature. The added tilt feature can be driven properly with the addition of the following two equations to the standard Singer software:

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$$\theta_1 = \theta_1 + K_1 \left(\frac{A_x}{3.1} - \theta_1 \right) \Big|_0^{77^\circ}$$

$$\theta_2 = \text{maximum of } \{0., (\theta_1 + K_2 \frac{A_x}{3.1} - \frac{77}{90})\}$$

where

 A_x = total longitudinal acceleration K_1 = rate limiting constant K_2 = scaling constant θ_1 = tilt axis angle θ_2 = tilt term of 6 DOF pitch axis

3.3.7.5. MCC Interface TLM, DCS, Trajectory

The computer-to-computer interfaces between the Mission Control Center and the Shuttle Mission Simulator will be accomplished by providing interface buffers and hard line data transfer equipment between the two computers. The seven general buffer areas required in the SMS computer complex is shown pictorially in Figure 3.3.7.5.

The Target Vehicle buffer will consist of approximately six words of data containing target vehicle identification, three commanded attitude words, a horizontal or vertical reference word, a time ignition word, and the time of burn. This data will enable MCC to maneuver the simulated target vehicles in the SMS by command and for the simulation of the target vehicle dynamics to be realistic for visual conditions.

The Digital Command System or the Up Data Link will be simulated by the SMS computer buffer accepting and decoding the MCC created command words. These commands provide the communication link for transfer of the MCC computed state vector data to the Shuttle GNC computer. The transferred state vector should contain ground equipment and data reduction propagated errors similar to the real world. System commands will be decoded by the DCS program for use by the vehicle systems.

The computer mode of operation and time will be transferred on a two-way basis with both computers providing data to the other. Master clock time data words will be generated by MCC for use in the SMS. In non-integrated modes the SMS will provide it's own time base.

The trajectory data buffer provides the master event time data and state vector data. The data buffer will provide for unpacking two words of discrete configuration data parameters, and time words for frame time and liftoff time.

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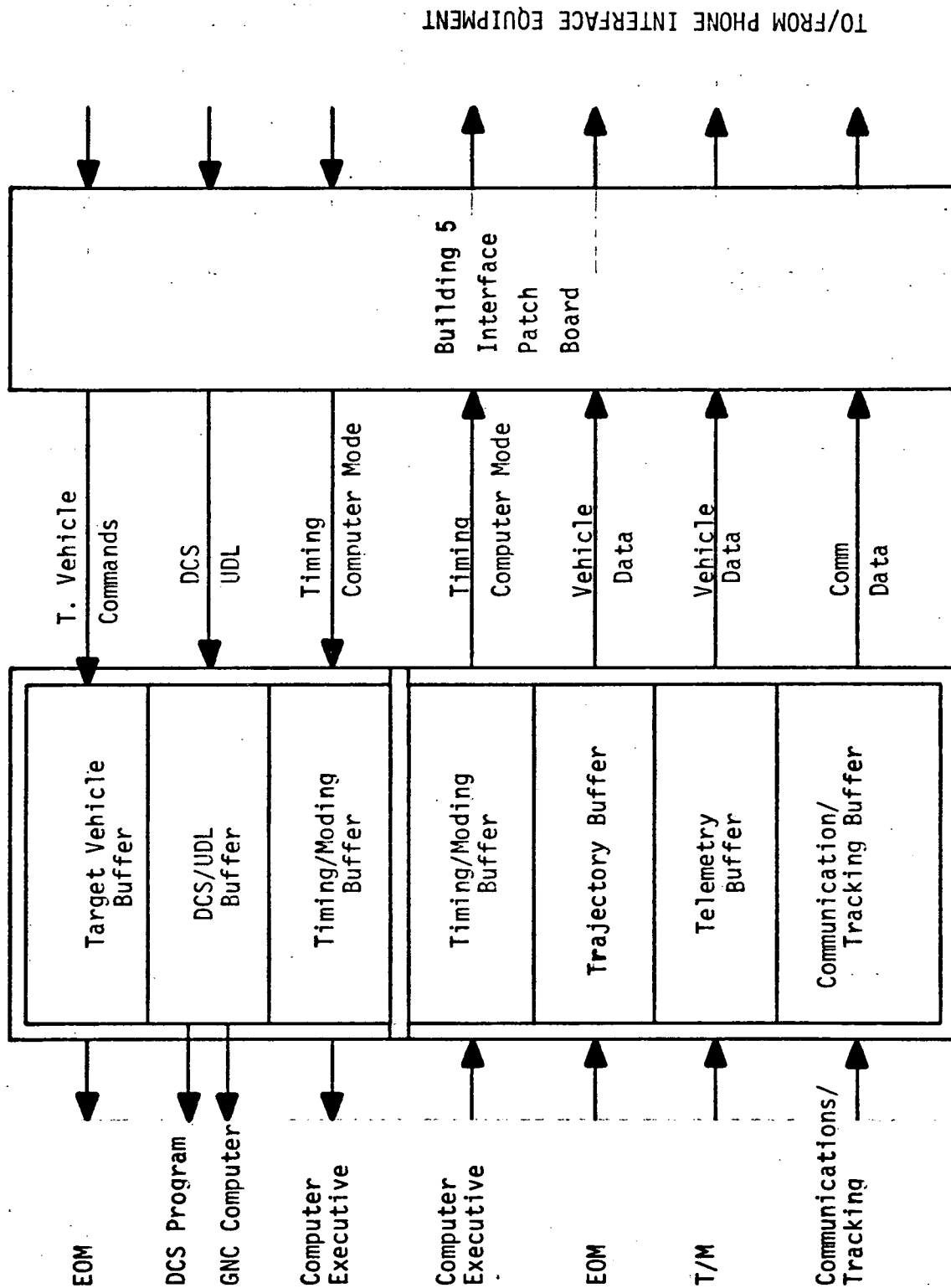


Figure 3.3.7.5-1
SMS INTERFACE-COMPUTER BUFFER

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Vehicle data for state vector position and attitude are supplied to GSSC/MCC for nine target vehicles and the shuttle. The nine target vehicles include the two solid rocket engines, the external tank, a free flying vehicle, and five payload targets. The packed discretes will identify whether the targets are attached or unattached.

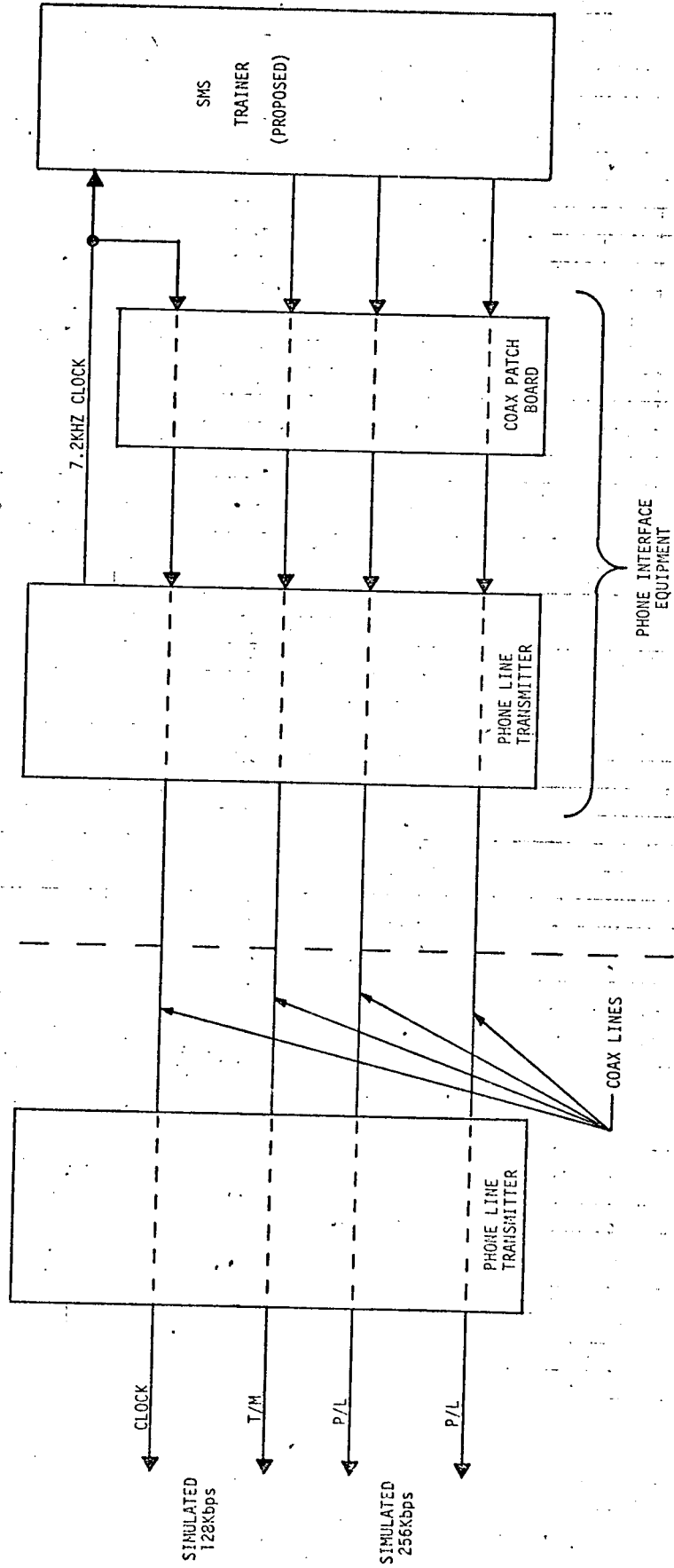
The shuttle vehicle telemetry data will be provided to MCC by blocks over coax cable. The data block transfer rate will be established at ten per second or 52Kbs. Spare coax cable will allow simultaneous transmission of the payload 1.7 MHZ data when that task trainer(s) is added. No software is provided for payload dedicated telemetry on the 1.7 MHZ subcarrier. Payload data which is transmitted on the 1.024 MHZ subcarrier will be provided. The maximum rate of data transfer over existing equipment is approximately one-half the real world system rate of 128 Kbs.

The communication/tracking buffer will provide voice and data recorder status and transceiver status along with transmitter output power to MCC. MCC will be required to calculate if an air to ground voice/data link is possible.

Each of these buffer areas may be combined with other buffer areas so as to fully use the data transmission link capability. Typical overall interfaces between the computers in Building 5 and the GSSC/MCC complex is shown in the following figures.

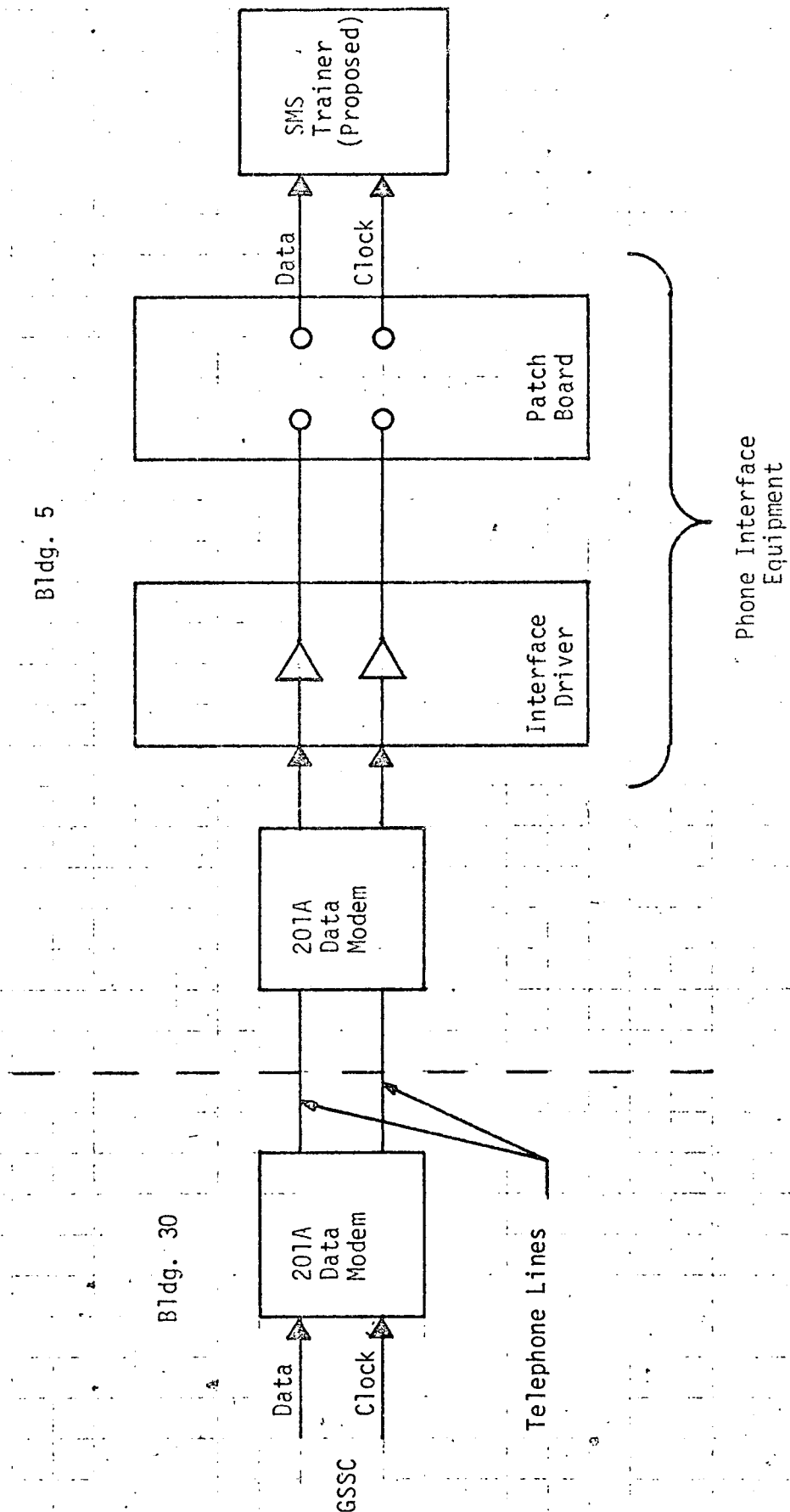
BUILDING 30

BUILDING 5



3.3.7.5.-2 TELEMETRY INTERFACE

Figure 3.3.7.5.-3 Command Interface Bldg. 30/Bldg. 5



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BUILDING 5

Phone Interface Equipment

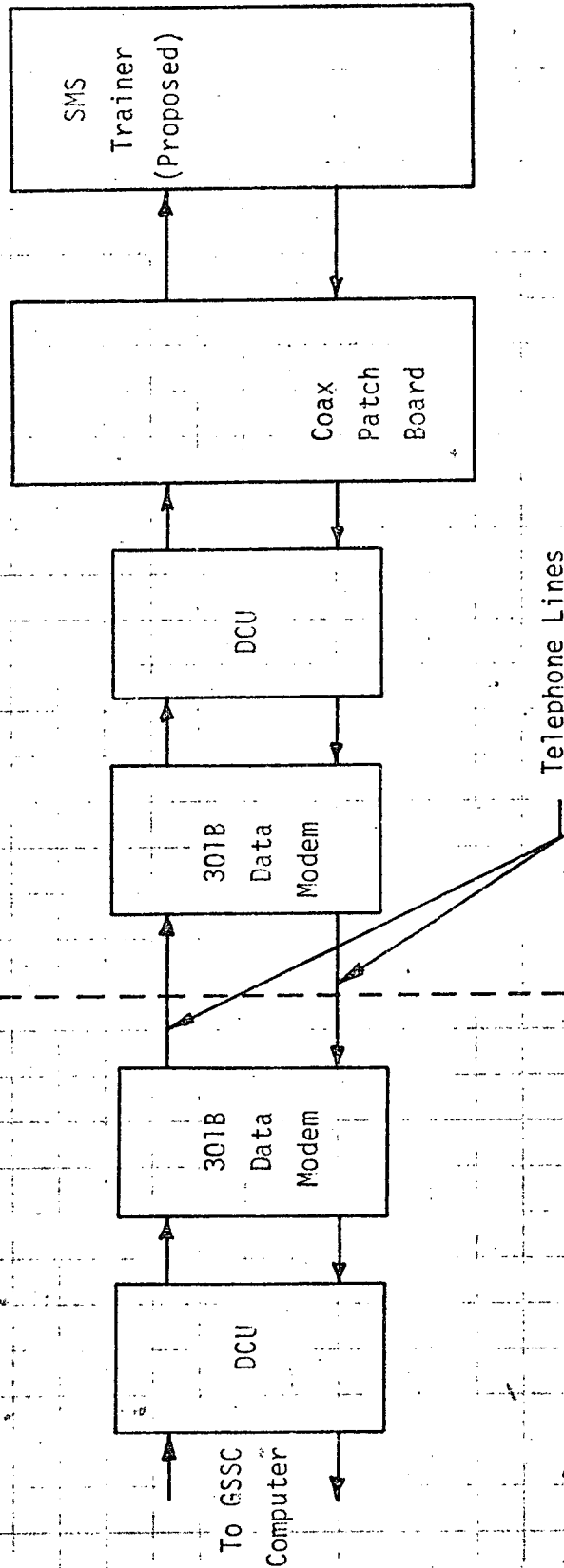


Figure 3.3.7.5.-4

SMS TRAJECTORY, TIMING, MODE, COMMUNICATION,
AND TARGET VEHICLE INTERFACE

3.3.7.6 Instructor Aids

The shuttle systems instructor will be provided with computer generated displays to reduce simulator data into a more directly useable training tool. These displays will use both digital and graphics as a means of presentation of data. The displays will also provide software system test and checkout capability without using crew station meters and displays. In addition parameters generated for internal software simulation usage will be provided.

The following examples are used to indicate the types of displays that are feasible and in some cases are in use in existing simulators.

A combination of graphics and digital display will be used for the electrical system power balance and distribution. The display will contain nodal current summations, bus voltages, inter-bus currents, and inter-bus circuit breaker status. Another display will be dedicated to a summation of the individual and collective bus loads for the AC buses and DC buses. Individual displays will also be provided for relay state, voltage, current, heat, malfunctions active for various components of the electrical system such as regulators, batteries, chargers, inverters, and generators. This type of presentation is typical of all systems for the on-board system test and support displays.

"Predicter" displays will provide the instructor a means of determining the condition or state of consumables, energy, or communication linkage at a future time point. For example, the "Communication Predictor" would display the next ground station to be acquired and the estimated time until line-of-sight is acquired. This predictor is anticipated to be limited to orbital operations using STDN stations only. The Energy Management graphic display is a type of predictor which shows the estimated down range and cross-range capability of the vehicle based on its altitude, speed, and aerodynamic characteristics. The energy management display will also graphically display the primary and secondary landing sites and runway

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orientation, wind direction, ideal approach pattern, etc. In addition to these displays, an estimated system capability could be displayed for electrical consumption rate versus total power available (from batteries, APU's, fuel cells, etc.) or for water consumption versus water quantity on hand and fuel cell water to be generated. Such displays would provide the instructor with a means of estimating vehicle status at a future time point based on inserted system malfunctions. A ground track predictor display could be used to display recent and anticipated ground track against continental outlines and STDN stations (and their approximate communication ranges) during orbital operations. Capabilities similar to those of the current CMS ALOS program could be provided, including sequential lists of STDN stations to be acquired over an interval of future time, and their acquisition and loss times (assuming no burns) during orbital operations. A capability could be provided to calculate time of closest ground track approach on the next orbit to a given earth location, as well as other parameters at the instant of closest approach such as altitude, range and bearing to the ground location, and line-of-sight elevation angle at the ground location.

A state vector generation program similar to the CMS-STAT program could be included, to permit trajectory reset of the shuttle or a target vehicle to any desired translational state. That translational state could be specified by ordinary rectangular coordinates in any of several coordinate systems, by orbital elements, by ground-projected location and local horizontal velocity properties, or by any of several other methods. Assuming a MCC role in orbital burn targetting, a package of targetting and burn sequencing programs could be provided for instructor use operating directly off simulator EOM data. Such a system, similar to that currently existing in the CMS MTP program package, would permit the instructor to "simulate" the RTCC, and possess information analogous to that of a MCC controller. Existing CMS targetting programs output such data as burn time, burn duration,

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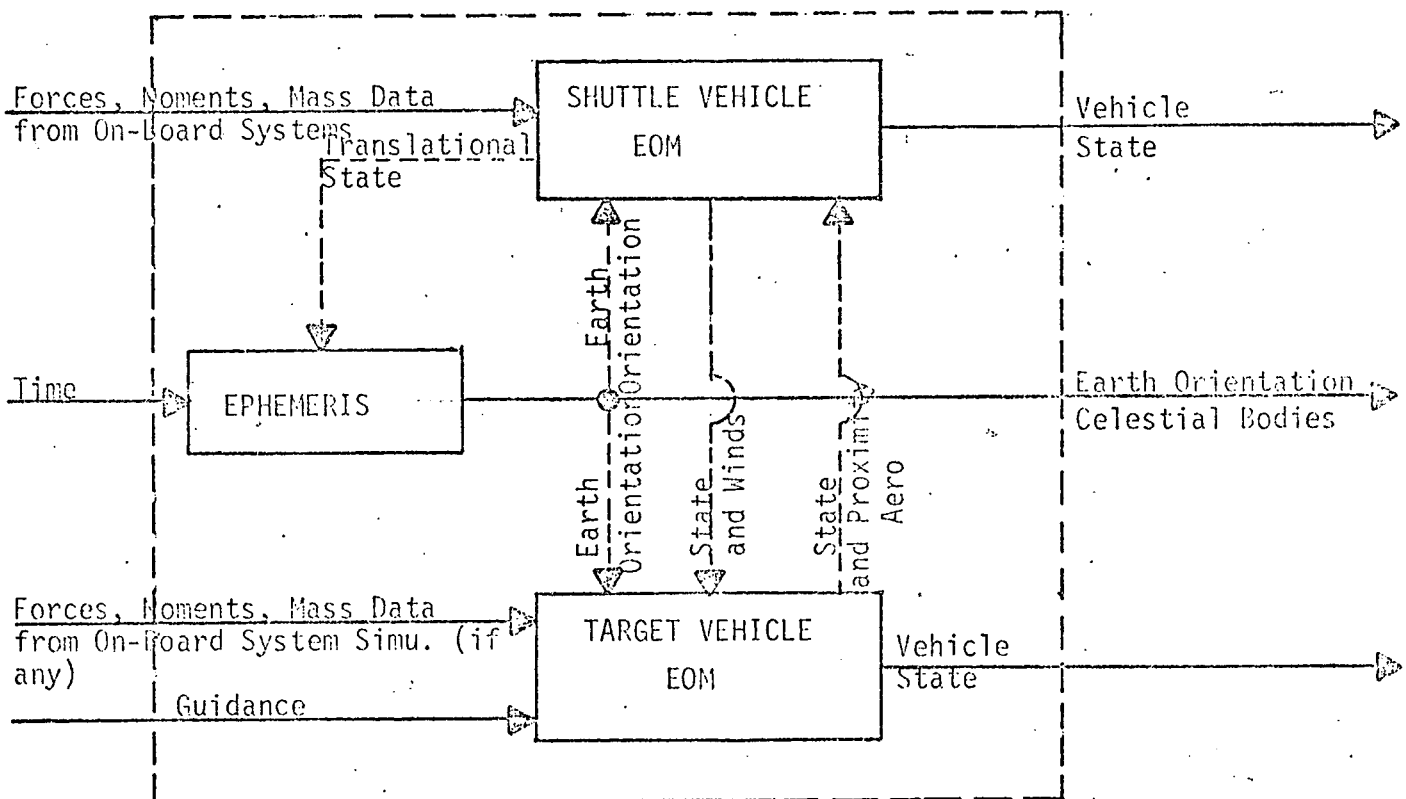
velocity to be gained along each axis, burn attitude, etc.

The use of an all attitude platform will reduce platform alignment problems, and increased shuttle autonomy may further impact ground participation in platform realignment. However, it is desirable to avoid the "gimbal-flip" region with 4-gimbal platforms, so platform realignments may still be made. If the ground has a role in this activity, an alignment generating routine analogous to the CMS RFMT program may be desirable.

3.3.8 Equations of Motion

The equations of motion system will simulate the dynamic and physical environment for the shuttle vehicle and each target vehicle. Inputs to the equations of motion include forces, moments, mass data from simulated on-board systems, and guidance-type inputs to the generalized target vehicle propulsion systems. The equations of motion system is conceptually subdivided as shown below:

EQUATIONS OF MOTION



A number of coordinate systems will be used to simulate vehicle dynamics.

The following symbols will be used for coordinate systems:

T coordinate system (earth centered) - epoch at reset point

X-axis: intersection of true equator and true ecliptic at epoch, positive toward vernal equinox.

Z-axis: true earth north-polar spin axis at epoch.

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Y-axis: completes right-handed orthogonal triad.

S coordinate system (earth centered)

X-axis: intersection of mean equator and mean equinox at epoch 1950.0, positive toward vernal equinox.

Z-axis: mean earth north-polar spin axis at epoch 1950.0.

Y-axis: completes right-handed orthogonal triad.

E coordinate system (earth centered)

X-axis: intersection of earth equatorial plane and plane of Greenwich meridian, positive out at zero longitude.

Z-axis: Earth north-polar spin axis

Y-axis: completes right-handed orthogonal triad.

F coordinate system (earth surface fixed) - flat earth system

X-axis: positive north

Y-axis: positive east

Z-axis: positive down

B coordinate system (vehicle center of mass centered)

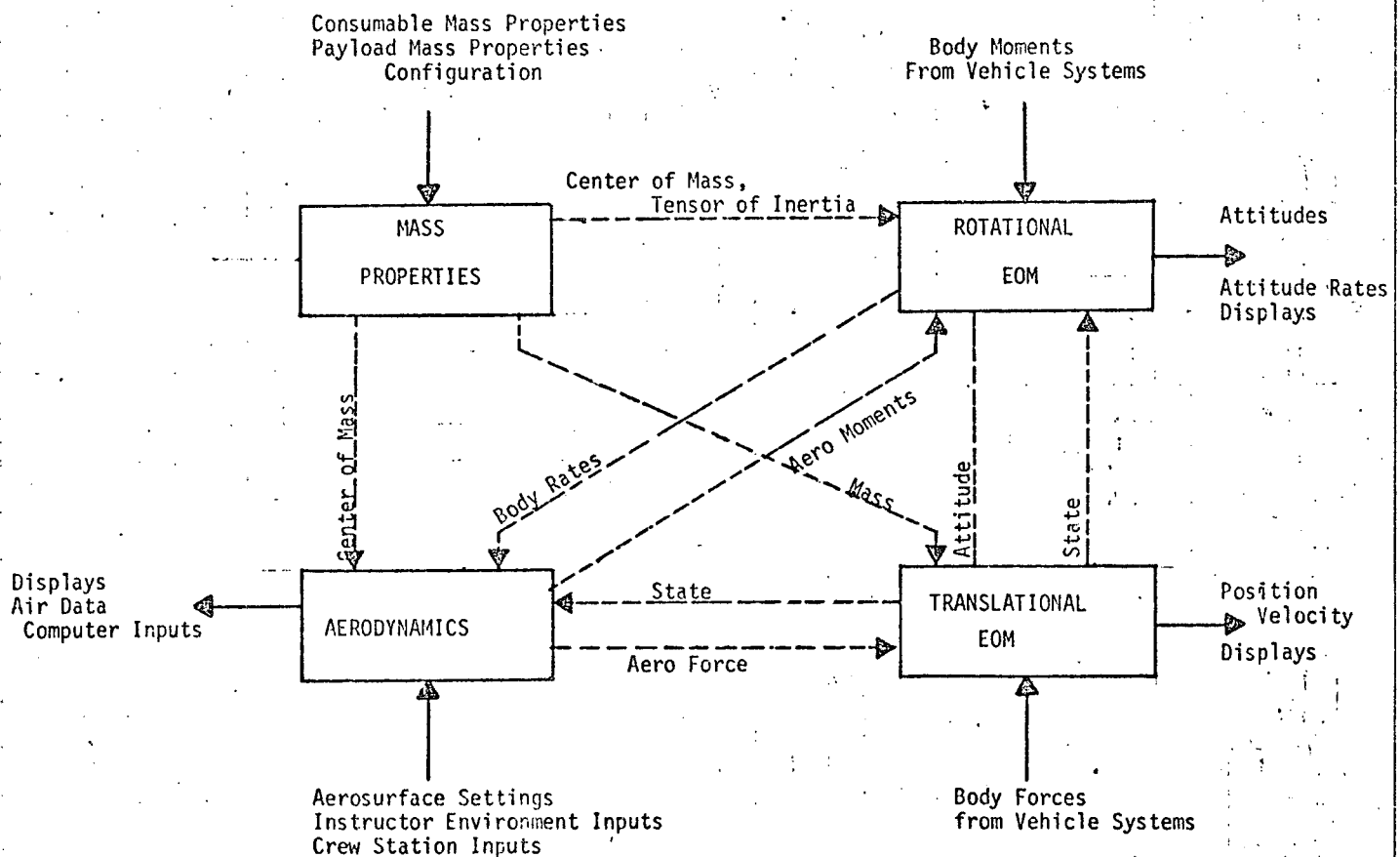
X-axis: orbiter fuselage reference line, positive forward.

Z-axis: perpendicular to X-axis in orbiter symmetry plane, positive down.

Y-axis: completes right-handed orthogonal triad.

3.3.8.1 Shuttle Vehicle

The shuttle vehicle equations of motion will provide a complete simulation of vehicle rotational and translational dynamics. The equations will operate under all shuttle vehicle space and ferry mission configurations. Inputs to the shuttle vehicle equations of motion will include body forces and moments from vehicle systems, aerosurface settings, instructor-determined environment inputs, consumable and payload mass properties, and vehicle configuration. From this information, the position, velocity, attitude, and attitude rate will be determined, as well as other parameters listed in the following discussions. The conceptual design of the shuttle equations of motion is divided into four subsystems as illustrated below:



3.3.8.1.1 Translational EOM

The simulated shuttle vehicle translational equations of motion will maintain vehicle translational state, given body forces, vehicle mass, and vehicle orientation in terms of the direction cosine matrix relating body fixed coordinates to EOM reference coordinates. Body forces which will be summed to obtain total body force are:

SRM thrust

MPS thrust (including venting)

OMS thrust

RCS thrust

ABPS forces

Gear/Braking forces

Drag Chute forces

Aerodynamic forces (including proximity and ground effects)

Payload Manipulation forces

Docking forces

The body forces are then transformed to the appropriate EOM reference coordinate system (T coordinate system or appropriate F coordinate system), and divided by total vehicle mass to obtain vehicle body acceleration. During orbital flight, (which may be defined as flight at orbital velocity with sustained body acceleration less than $3 \frac{\text{ft}}{\text{sec}^2}$), an Encke orbit determination scheme together with Runge-Kutta integration will update vehicle state each 8 seconds. Vehicle state will be estimated in the intervening time by extrapolating gravity from past values calculated at 8 second intervals, and integrating directly to find velocity and position. Position and velocity deltas resulting from body accelerations will be included in the appropriate fashion into the Encke accumulated central body deviation state vector. An Encke scheme is selected over a Cowell scheme because

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of the former's substantially higher accuracy, permitting a relatively larger step size with superior precision. Encke is also very preferable for accomplishing rapid step-ahead. Runge-Kutta integration is used in preference to a high-order predictor-corrector integrator (e.g., Adams-Moulton) because of Runge-Kutta's very high precision in handling such gravitational accelerations, and the fact that it is self-starting. Predictor-correctors require a number of past values which, due to the stringent accuracy requirements, would probably have to be initialized in this case using Runge-Kutta, thereby substantially complicating the program. Far less stringent accuracy requirements exist on the past values for the extrapolation, since extrapolation errors do not propagate. Update each 8 seconds should assure update "jumps" of less than 1 foot in position. During other than orbital flight, vehicle state will be maintained using a low-order predictor scheme (e.g., rectangular or Adams) and a Cowell orbit determination scheme (due to the very substantial perturbative accelerations). During pre-launch (i.e., prior to hold down arm lifting), the state vector will be recalculated directly using the earth rotation rate, rather than integrated. State will be maintained in the T system during space flights, until final approach, at which time translation to the appropriate flat-earth F coordinate system will be accomplished. A flat-earth F coordinate system will be used for ferry flights. Gravitational accelerations will be calculated using the J_2, J_3, J_4 , and J_{22} harmonics during regimes in which the T coordinate system is used. During regimes in which the F coordinate system is used, a central body gravitational field with magnitude that of 30° latitude will be used. Parameters output for other systems and displays at all time, will include:

vehicle state (includes vehicle altitude)

vehicle latitude and longitude

vehicle ground track heading

vehicle relate velocity

vehicle flight path angle

In regimes in which state is maintained in the T coordinate system, the following additional outputs will be provided:

vehicle altitude

vehicle radius magnitude

vehicle inertial velocity magnitude

vehicle state in S and E systems

orbital elements (semi-major axis, parameter, eccentricity, apogee, perigee, inclination, inertial longitude of ascending node, true anomaly, eccentric anomaly, inertial longitude of perigee)

time of next orbital sunrise/sunset

An iteration rate of 20 per second is specified. Since aerodynamics, MPS, RCS, and ØMS programs are iterated at this rate, a sizable part of translational ROM must operate this fast to properly interface. It is considered desirable to also operate the remainder of the program at the same rate to obtain accurate gravitational effects. Although all display parameters are shown in the conceptual design as being updated each 50 milliseconds, this is probably not necessary in all cases. Thus, if time is critical, some of these may be updated less frequently, at the cost of some complication of the conceptual design. The conceptual design is sketched in figure 3.3.20.1.1-1. All coordinate transformation, except that from B coordinates to I or F coordinates, will be calculated in block (7) or block (15) thereof. In step-ahead mode, the Encke/Runge-Kutta loop only will be used for integration (blocks (11) through (13)) and the extrapolation logic bypassed. A larger step size than 8 seconds can be utilized (one minute would not be excessive). The only non-gravitational perturbative force included during step-ahead will be orbital drag. It will be calculated using the last values of aero coefficients

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and angle of attack obtained prior to entering step ahead. Dynamic pressure will be recalculated, the forces and accelerations re-computed and approximately transformed to the T coordinate system once per step-ahead step. Drag will be assumed constant over one integration step.

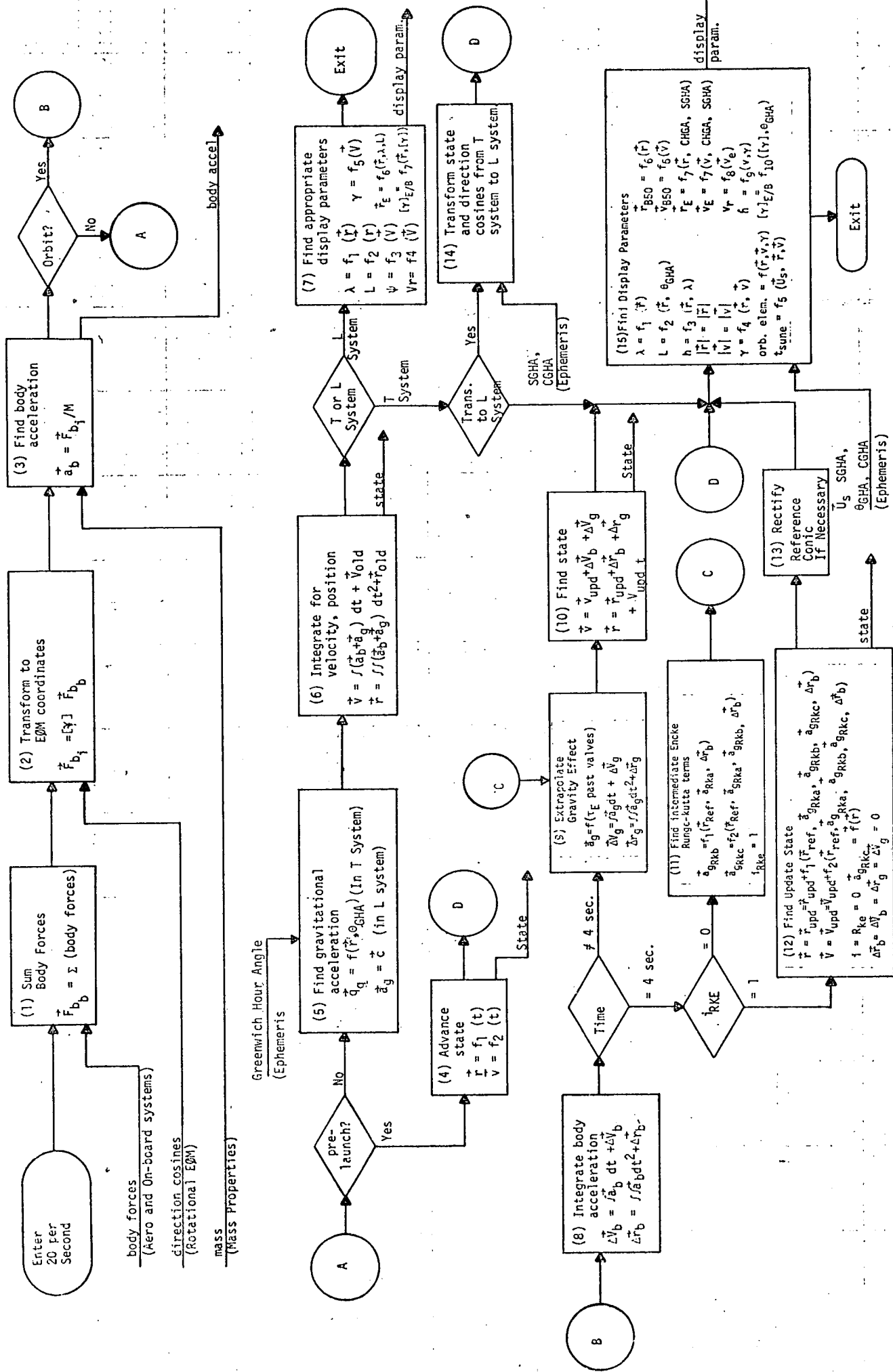


FIGURE 3.3.8.1.1-1

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SYMBOL DICTIONARY

\vec{A}_b	Total body acceleration	\vec{V}	vehicle velocity, T or L coords.
\vec{A}_g	Gravitational acceleration	\vec{V}_{B50}	vehicle velocity, S coords.
\vec{A}_{grka}	Intermediate gravitational acceleration	\vec{V}_E	vehicle velocity, E coords
\vec{A}_{grkb}	Intermediate gravitational acceleration	\vec{V}_{upd}	vehicle velocity at last low speed update
\vec{A}_{grkc}	Intermediate gravitational acceleration	V_r	vehicle relative velocity magnitude
CGHA	Cosine of θ_{GHA}	γ	flight path angle
\vec{F}_{bb}	total body force, B coords.	$[\gamma]$	direction cosine matrix
\vec{F}_{bi}	total body force, T or L coords.	$[\gamma]_{E/B}$	direction cosine matrix between E coordinates and B coordinates
h	vehicle altitude	$\Delta \vec{V}_b$	delta position due to body force since last update
\dot{h}	altitude rate	$\Delta \vec{V}_g$	delta position due to gravity since last update
i_{RKL}	Runge-Kutta logic flag	$\Delta \vec{V}_b$	delta velocity due to body force since last update
L	vehicle longitude	$\Delta \vec{V}_g$	delta velocity due to gravity since last update
M	total vehicle mass	θ_{GHA}	Greenwich hour angle
\vec{r}	vehicle position, T or L coords.	λ	vehicle longitude
\vec{r}_{B50}	Vehicle position, S coords.	ψ	vehicle ground track heading
\vec{r}_E	Encke reference vehicle position		
\vec{r}_{upd}	vehicle position at last low speed loop update		
SGHA	sine of θ_{GHA}		

3.3.8.1.2 ROTATIONAL EOM

The simulated shuttle vehicle rotational equations of motion will maintain vehicle attitude and attitude rates given current vehicle position, center of mass, inertia tensor, and vehicle body forces and moments. Body force, and moments included in the calculation of vehicle rotational dynamics are:

SRM thrust

MPS thrust (including venting)

OMS thrust

RCS thrust

ABPS forces

Gear/Braking forces

Drag chute forces

Aerodynamic moments (including proximity and ground effects)

Payload Manipulation moments

Docking Moments

Body moments resulting from body forces are calculated using the fixed position of the application point and the current position of the vehicle center of mass. The rotational effects of moving payload doors/space radiators will be calculated, and included within the rotational dynamics. Gravity gradient torques will be calculated and included in the aggregate body moments. Euler's equations will be solved to obtain angular accelerations, and will be integrated to obtain angular rates. Rates and attitude changes due to prelaunch constraints will be simulated prior to liftoff. The structural body fixed coordinate system will be used for the inertia tensor and angular velocity. The use of principal axes results in a considerably simplified form of Euler's equations. However, this advantage is largely negated if the orientation of the principal axes tend to move substantially with respect to body axes in time. Time, and especially core, required to calculate the body-to-principal axes

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transformation tends to erase the advantages of principal axes, and more. It appears currently that during many mission phases, the principal axes migrate sufficiently much to require recalculation. Thus, principal axes are not used. This choice should be re-evaluated as later data becomes available. The direction cosine matrix will be obtained from the angular velocity vector directly using self-normalizing difference equations. The accuracy and conceptual simplicity of this method is preferred to direct integration or the use of quaternions. Euler angles with respect to local horizontal are then calculated for purposes of display using the direction cosines. The direction cosine matrix will transform from the D coordinate system to either the T or F coordinate system, depending upon which system is the prime EOM coordinate system at the time. Rotational dynamics should be updated 20 times per second during regimes when a thrust vector control system or aero-surfaces are in use for good response characteristics. At least part of the system must be iterated at that rate during orbital coast modes to properly interface with the simulated RCS. Under those circumstances, it seems desirable to iterate the program at that rate at all times. The conceptual design is illustrated in Figure 3.3.8.1.2-1.

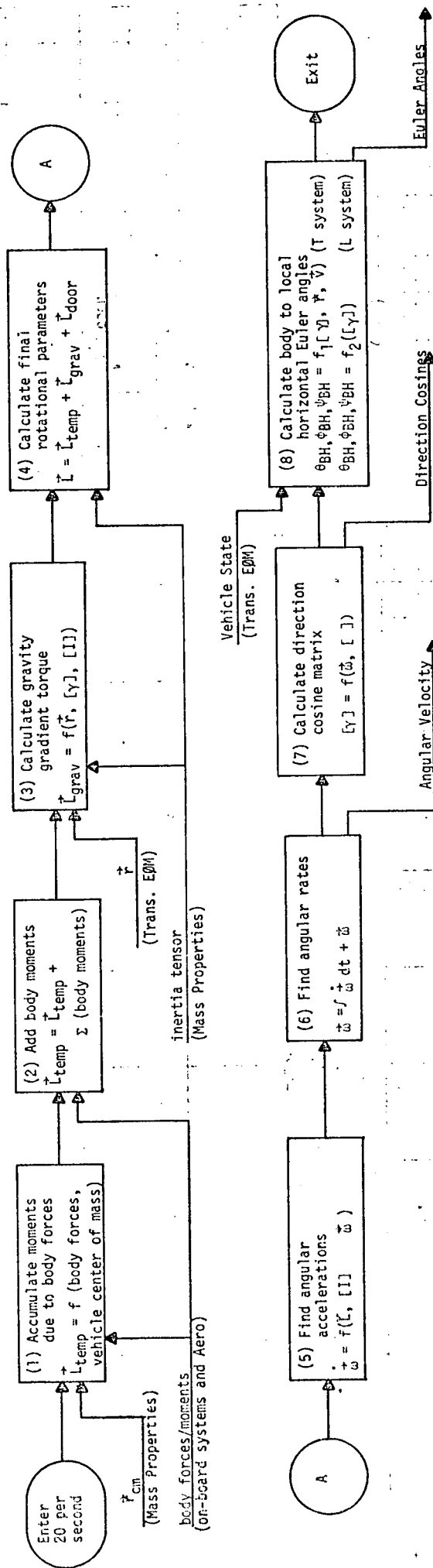


FIGURE 3.3.8.1.2-1

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SYMBOL DICTIONARY

 $[I]$ Vehicle inertia tensor \rightarrow
 L total body torque \rightarrow
 L_{door} torque due to moving doors \rightarrow
 L_{grav} gravity gradient torque \rightarrow
 L_{temp} torque accumulator \rightarrow
 r vehicle position \rightarrow
 V vehicle velocity $[\gamma]$ direction cosine matrix θ_{BH} local horizontal pitch ϕ_{BH} local horizontal roll ψ_{BH} local horizontal yaw \rightarrow
 ω angular velocity \rightarrow
 $\dot{\omega}$ angular acceleration

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The shuttle vehicle is a complex structure composed of an aircraft, an external fuel tank, two strap-on solid rocket motors and a payload. During powered flight this structure is subjected to loads such as engine thrust, fuel slosh and aerodynamic forces. These forces cause the vehicle to bend and result in structural vibrations primarily at certain predetermined frequencies. These vibrations in turn feed into body-mounted accelerometers and rate gyros which provide the sensor data used in the vehicle control system rate-feedback and load-relief control loops. These accelerometers and rate gyros are normally placed in a vehicle in a manner to minimize the sensing of the transient effects due to bending, fuel-slosh and aeroelasticity. Filters are then added to further reduce these effects as they are seen by a control system. If these provisions are adequate to filter out these vibrational modes from the shuttle control system, it is unnecessary to simulate these dynamics in an astronaut training device, and a rigid body simulation will suffice.

The shuttle vehicle apparently will include three rate gyro packages and three bodymounted accelerometer packages. Each rate gyro package contains three rate gyros which are mounted mutually perpendicular to one another. The accelerometer packages each contain two accelerometers. These are normally perpendicular to one another and lie in a plane perpendicular to the vehicle center-line. Each rate gyro and each accelerometer may be mounted apart from the others in its package. The inputs to these 15 sensing devices will be simulated as outputs from the bending model should flexible body dynamics be determined to be necessary.

If the bending exceeds the control system's capabilities, the following method of bending simulation is recommended. The shuttle vehicle can be idealized into a structure of rods, tubes and panels upon which

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are acting the external forces mentioned above. The bending of a structure under load is the cumulative result of the bending of the individual elements composing the structure. A matrix method is recommended for the handling of the quantity of data arising in the solutions of flexure calculations of such a complex structure. This method presents data in a form suitable for use in the normal calculatory procedures of a high speed digital simulation and allows simple expansion of the program is required. The bending equations of motion for the idealized system are defined by a series of matrix multiplications where the matrices describe the thrust force, structure elements, fuel slosh effects and aerodynamic forces.

The program will be computed at a rate of at least ten times per second. Program outputs will consist of rates and accelerations sensed by the control system devices and increments to rigid body forces and moments resulting from body flexing.

The vehicle's motion can be affected by fuel slosh. The shuttle contains five reaction control system tanks in the orbiter's nose and three tanks in each of the orbital maneuvering system (OMS) engine pods. The payload bay is capable of containing up to six fuel tanks. There are four fuel tanks in the OMS pods, two per pod. The external tank consists of two main tank compartments. Neglecting the cryo tanks this accounts for 23 tanks of fuel that might need simulating.

During the first stage of flight the slosh dynamics have been estimated to be in a frequency range between 0.5 and 0.7 Hertz. During the second stage of flight this frequency is expected to be between 0.3 and 0.5 Hertz. One of the reasons slosh is critical is due to the forward location of the LO₂ tank. Slosh effects this far away from the center of

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mass can have a pronounced effect on the rotational dynamics of the vehicle. The choice of which tanks must be simulated will be a function of those sloshing effects which cannot be filtered out of the control system effectively and which bending effects, which are in part a function of slosh, cannot be filtered out of the control system.

The simulation of fuel slosh may be accomplished by assuming the fuel to act similar to a spring-mass-damper system tied to the airframe and a rotatable inertia coupled to the vehicle structure through the damping action of internal baffles. The slosh model will supply the mass center vector of the fuel for each tank to the equations of motion. It will also supply the forces produced by fuel motion as the vehicle and fuel exchange momentum. Forces required by the bending model at other critical points in the vehicle will also be supplied by the fuel slosh model.

The model requires several coefficients and their interaction that will be defined as more design data becomes available. This will allow a description of the forces in each plane accounting for any cross-coupling that exists.

The slosh model program will be computed as fast as any program that uses its outputs. This is 20 times per second, the execution rate of the rotational equations of motion.

The following figure depicts a functional flow of an approach that might be used should flexible body dynamics simulation become necessary. The necessity of this simulation will be determined as the shuttle design and dynamic characteristics become better defined. Aeroelasticity simulation is discussed further in Section 3.3.8.1.4.

SLOSH, BENDING AND AEROELASTICITY

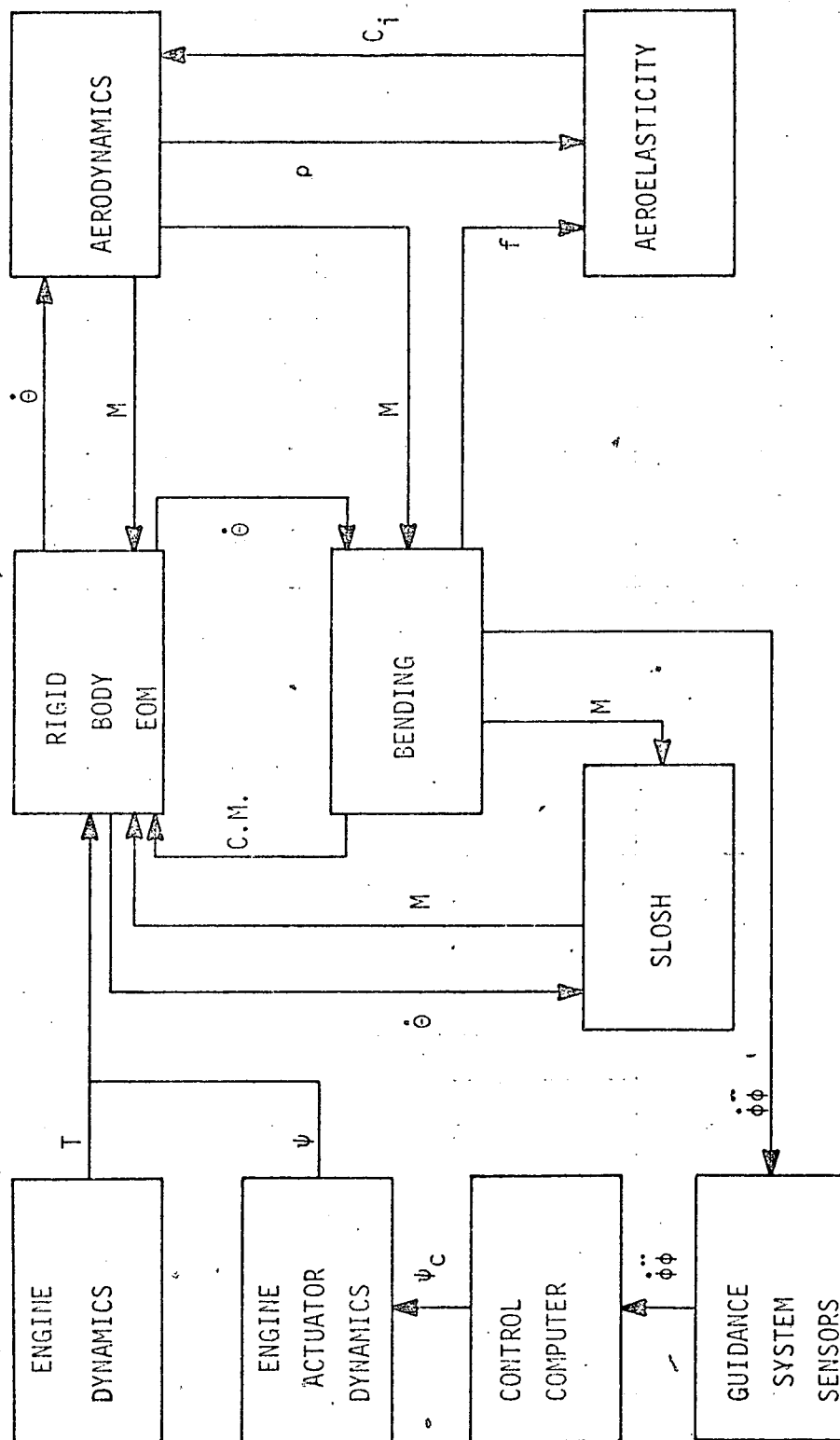


FIGURE 3.3.8.1.2-2

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It is estimated that the addition of body bending and fuel sloshing will result in the following core and time increments:

	SLOSHING	BENDING
Increase in number of executable instructions	450	4,500
Increase in number of instructions executed per second	170,000	260,000
Increase in data pool	1,600	1,000

3.3.8.1.3 Mass Properties

The shuttle vehicle mass properties simulation must calculate the current vehicle mass, center of mass, and inertial tensor for the vehicle equations of motion. Mass properties will be calculated in the B coordinate system. In order to accomplish this, the mass properties simulation obtains information on mass and mass distribution of on-board consumables from the simulated vehicle systems, and on vehicle configuration from the environmental control system, payload accommodation system, simulated docking system, simulated SRM's, and simulated external tank. The mass properties simulation accepts the following specific dynamic inputs:

	Consumables		
	Mass	Center of Mass	Inertial Tensor (about own C.M.)
MPS Fuel/Oxidizer	X	X	X
SRM Fuel	X	X	X
RCS Propellant	X	X	
OMS Fuel/Oxidizer	X	X	X
APBS Fuel	X	X	X
APU Fuel	X	X	
Cryogenics Reactant	X		
Water	X		
GN ₂	X		

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Configuration

SRM's	Attachment boolean
External tank	Attachment boolean
Payload Doors	Center of mass, inertia tensor about own C.M.
Space Radiators	Center of mass, inertia tensor about own C.M.
Payload Manipulator	Center of mass, inertia tensor about own C.M.

Target Vehicles

Each target vehicle	Attachment/docked status, mass, center of mass (shuttle body coordinates), inertia tensor about own C.M.
---------------------	--

Other consumable or configuration changes are not expected to be of sufficient magnitude to warrant simulation. The simulated mass properties must be updated ten times per second during boost. At other times, however, mass flows are sufficiently low to permit slower iteration rates. With approximate OMS mass flow of $.5 \frac{\text{slug}}{\text{sec}}$ per engine, ABPS mass flow of $.6 \frac{\text{slug}}{\text{sec}}$, and RCS mass flow of $.15 \frac{\text{slug}}{\text{sec}}$ per jet, an update rate of once per two seconds should be feasible. However, to correctly simulate docking/payload attachment effects, must faster response is required. Whenever any change in docking or attachment status takes place, its effect should be reflected as soon as possible in vehicle mass properties. Thus, in orbit, the portion of the program which handles docked/attached configurations is updated ten times per second. The conceptual design is illustrated in figure 3.3.8.1.3-1.

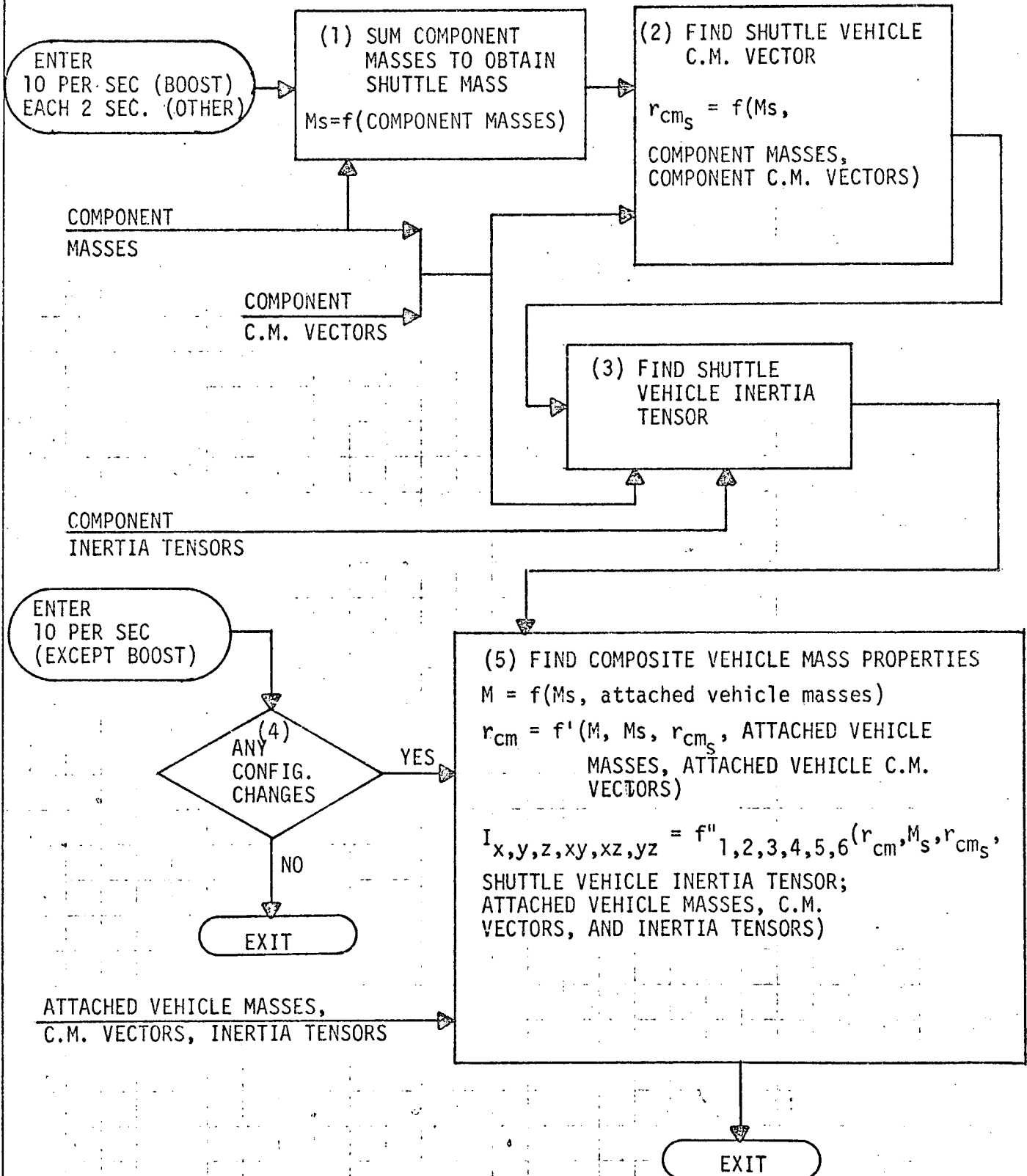


FIGURE 3.3.8.1.3-1

Symbol Dictionary for Figure 3.3.8.1.3-1 I_x cluster x-axis moment of inertia M total cluster mass I_y cluster y-axis moment of inertia M_s shuttle vehicle mass I_z cluster z-axis moment of inertia

(exclusive of payloads)

 I_{xy} cluster x-y product of inertia \vec{r}_{cm} cluster C.M. position I_{yz} cluster y-z product of inertia

vector (body coordinates)

 \vec{r}_{cm_s} shuttle vehicle C.M.position (exclusive of
payloads)

The consumable masses will be added to the vehicle dry mass, a reset constant, to obtain M_s . Then, \vec{r}_{cm_s} will be calculated using the consumable masses and mass centers, masses and mass centers of configuration changeable portions, and the mass and mass center of the remainder of the vehicle. Consumable mass centers not specified above as calculated dynamically will be represented by reset constants. Shuttle vehicle inertia tensor (less payloads) will be calculated using the component masses, mass centers, and inertia tensors specified above (except for target vehicles), as well as mass properties of the remainder of the vehicle. When a component's inertia tensor is not specified above as calculated dynamically, it will be assumed that all its mass is concentrated at its mass center. Once shuttle vehicle (less payload) mass properties are found, they are then combined with mass properties of attached payloads to obtain cluster mass properties.

3.3.8.1.4 Aerodynamics

The simulated shuttle vehicle aerodynamics provides forces and moments due to vehicle motion through the atmosphere to the shuttle vehicle equations of motion. Inputs to the simulated aerodynamics include vehicle position, velocity, altitude, and altitude rate (from translational EOM); direction cosine matrix and angular velocity (from rotational EOM); aerosurface deflections (from Aerosurface control); proximity aerodynamic effects (from target vehicle aeroflight aerodynamics); pilot barometric correction setting (from the crew station); and wind velocity/azimuth, gust settings, sea level temperature, and barometric pressure setting (from instructor station). Outputs include aerodynamic force and moment (both in the B coordinate system), ambient and dynamic pressure, true and indicated airspeed, indicated altitude, ambient outside air temperature, and angles of attack and sideslip. Vehicle position and velocity will be used to calculate velocity with respect to rotating atmosphere (taking due account of the current EOM coordinate system). Wind and rough air effects are then included to obtain velocity with respect to the moving atmosphere, which is then rotated to the B coordinate system. A prestored wind profile (velocity and azimuth) will be utilized, with instructor override capability. During spaceflight missions, provision will be made for differing wind profiles for boost and entry. During boost, orbit, and high-altitude phases of entry, nominal profiles of atmospheric density, temperature, and pressure versus altitude will be used. During low-altitude phases of entry, and during ferry flights, instructor control over atmospheric conditions will be provided through variable settings of sea level temperature and barometric pressure. In this regime, simulation of atmospheric properties will be based on pressure-altitude. During re-entry, delta-effects due to instructor settings will be gradually included below a specific altitude, until they are fully effective at a lower altitude, in order to provide smooth

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transition. Separate calculations of aerodynamic forces and moments are provided for each of the three principal configurations present during space missions, namely, orbiter + tank + SRM's (first stage), orbiter + tank (second stage), and orbiter alone. Orbiter alone calculations will be capable of simulating both the space mission and ferry mission configuration aerodynamic properties. Aerodynamic forces and moments will be computed in the B-coordinate system for both boost configurations and in stability axes during orbiter-alone configuration. Stability axis forces and moments will be transformed to the B-coordinate system before exiting the program. Aerodynamic coefficients will be simulated using combinations of functions of one, two, and/or three variables, constants, and mathematical expressions. The effects of vehicle elasticity on vehicle aerodynamics will be simulated in the conventional manner by introducing aeroelastic corrections into the aerodynamic equations. The general approach will be to generate aerodynamic characteristics of a "clean" aircraft in cruise status. Incremental effects of aerosurfaces, ground or target vehicle proximity, etc. will then be combined with the above to obtain all-condition performance simulation. Prime aerodynamic parameters will be simulated to extended values of angle-of-attack and sideslip to afford reasonable stalling characteristics. Definition of parameters upon which aerodynamic coefficients will be dependent was generally obtained from currently existing design data, which is incomplete. As additional data becomes available, parameter dependencies below should be reviewed and revised accordingly. During orbital phases, effects upon aerodynamic forces of aerosurface deflections will not be simulated. A high aerodynamics iteration rate during entry and ferry is desirable for proper simulation of higher frequency effects within pilot perception. A rate of 20 per second should be quite adequate to accomplish this. Current Saturn boost simulations have run successfully with aerodynamics update rates of 10 per second. However, the period during the max-q

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region in which aerosurface control is used on the shuttle may render desirable a higher update rate. Thus, at this time, a 20 per second rate is specified for boost as well. During orbital phases, aero effects are noticeable only after extended periods of time, and body rates (and therefore relative wind) do not change rapidly except over brief periods of time. Thus, an update rate of twice per second should be quite adequate in this phase. The aerodynamics conceptual design is sketched in Figure 3.3.8.1.4-1.

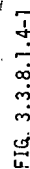


FIG. 3.3.8.1.4-1

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SYMBOL DICTIONARY FOR FIGURE 3.3.8.1.4

C_A	axial force coefficient	T_{SL}	sea level temperature
C_D	drag coefficient	V	vehicle velocity
C_L	lift coefficient	V_i	indicated airspeed
C_l	rolling moment coefficient	V_{rb}	velocity with respect to moving atmosphere (B coordinate system)
C_m	pitching moment coefficient	V_{ri}	velocity with respect to moving atmosphere (EOM coordinate system)
C_N	normal force coefficient		
C_n	yawing moment coefficient		
C_y	side force coefficient		
\vec{F}_{aero}	total aerodynamic force	V_{rt}	true airspeed
h	altitude	V_s	speed of sound
\dot{h}	altitude rate	α	angle of attack
Hg_{inst}	instructor baro setting	β	sideslip angle
Hg_{pilot}	pilot baro correction	$[Y]$	direction cosine matrix
h_i	indicated altitude	δ_a	aileron (differential elevon) deflection
h_p	pressure altitude	δ_e	elevon deflection
\vec{L}_{aero}	total aerodynamic moment	δ_r	rudder deflection
M_n	mach number	δ_{rf}	rudder flare
P_{amb}	ambient pressure	ρ	atmospheric density
P_s	stability axis roll rate	$\vec{\omega}$	vehicle angular velocity
q	dynamic pressure	ω_y	vehicle body-axis pitch rate
\vec{r}	vehicle position		
r_s	stability axis yaw rate		
T_k	absolute air temperature		
T_{OA}	outside air temperature		

Aeroelastic effects due to structural bending and torsion will be simulated should it become necessary to include flexible body dynamics in the shuttle simulation. The basic design structure of the system would apply additions and corrections to the non-dimensional stability coefficients in the vehicle aerodynamics program.

Aeroelastic effects will be simulated during a mated ascent, staging, entry/transition and cruise/landing operations. These effects can arise during these operations from any of the following:

1. Wing torsion and bending due to:
 - a. airloads in equilibrium flight,
 - b. differential elevon deflection,
 - c. "dead weight" distribution when the vehicle is subjected to a normal acceleration, and
 - d. elevon deflection.
2. Vertical tail torsion and bending due to rudder deflection.
3. Fuselage bending and torsion due to airloads on the vertical tail.
4. Fuselage bending due to "dead weight" distribution when the vehicle is subjected to a normal acceleration.

The magnitude of these simulated effects for any particular vehicle configuration of a particular flight condition is dependent on the following factors.

1. Dynamic pressure.
2. Airframe configuration.
3. Mach number.
4. Normal acceleration.

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Aeroelastic effects are primarily a function of dynamic pressure, q . By definition, $q = .5\rho V^2$, where ρ is the density of air and V is the true forward velocity. Since ρ decreases as altitude increases it is clear that q increases as Mach No. increases and altitude decreases. If it is assumed that aeroelastic effects increase with q , then it can be concluded that the magnitude of aeroelastic effects are largest when the vehicle is at high speed and low altitude.

The magnitude and more importantly, the sign of aeroelastic corrections to the rigid body stability coefficient depends to a large extent upon the configuration of the vehicle. In the case of shuttle, the overall configuration will change from launch to landing.

In addition to determining the effect of dynamic pressure, the flight Mach. No. is important in determining corrections to the stability coefficients. Since the distribution of air loads is altered as the Mach No. is changed, the resulting aeroelastic deflections are also affected and are especially critical in the transonic region.

Depending on the particular vehicle configuration, aeroelastic effects can be important under flight conditions involving normal accelerations other than one "g". When the vehicle is subjected to accelerations the dead weight of the body produces both torsional and bending deflections. The correct method for introducing these effects into the dynamics of the body is to provide equations of motion to account for the elastic degrees of freedom. However, if the motion of the airframe are assumed to be slow with respect to the elastic frame, the inertial effects of various concentrated masses relative to the entire mass can be neglected. It may be concluded that for a stabilized normal acceleration no additional equations of motion are

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required and aeroelastic effects may be taken into account by additions and corrections to the conventional equations of motion.

The conceptual design for aeroelastic simulation as illustrated in Figure 3.3.8.1.4-2 takes into account the four factors described and treats them as separate program models. To accurately simulate the effects due to dynamic pressure, airframe configuration, Mach No. and normal acceleration, shuttle data on aeroelastic response must be available prior to implementation.

In addition to the four models containing response data, a control program is required to read the data, interpolate, and output coefficient corrections at a compatible simulation rate.

Coefficients important to vehicle stability and control and most likely to be affected by aeroelasticity are: Cm_{α} , $Cm_{\dot{\alpha}}$, $Cm_{\delta e}$, Cm_q , CL_{α} , $CL_{\delta a}$, CL_p , $Cm_{\delta a}$, CL_{β} , and $Cm_{\delta r}$.

It is estimated that the addition of the above described aeroelastic simulation will result in an increase of 4,000 executable instructions in core, a timing increment of 240,000 instructions per second, and a data pool increment of 1,600 values.

AEROELASTICITY PROGRAM

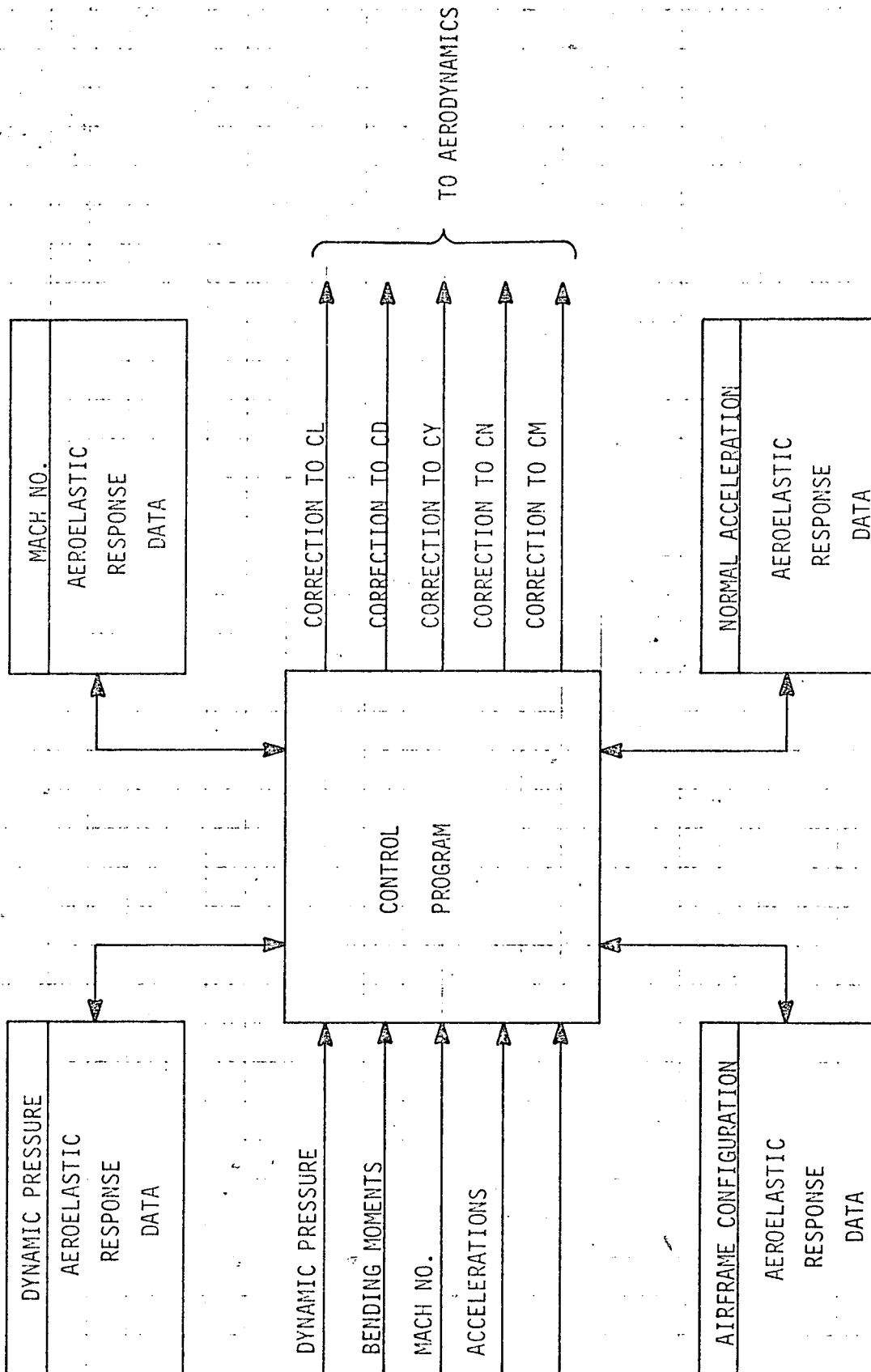


FIGURE 3.3.8.1.4-2

3.3.8.2 Target Vehicles

The target vehicle equations of motion will simulate translational and rotational dynamics for up to eight different target vehicles. The same basic logic will be used for each of the eight target vehicles, and is discussed below. The equations of motion will provide generalized simulations of rotational/translational propulsion systems, which may optionally be used for a given payload. Alternately, the equations of motion will be able to pick up rotational moments, translational forces, and mass flow from specialized payload simulation programs. The generalized propulsion systems will be configured to accept inputs from simulated generalized target vehicle guidance, or from either the instructor or simulated shuttle vehicle. Generalized propulsion and control simulations are used for the reasons stated in the rationale to the Shuttle Mission Simulator Requirements Report. To summarize some of the reasons, some target vehicle dynamics simulation will be required, especially during rendezvous and docking. Since the target vehicle may be active during part of rendezvous, and may control its own attitude during station-keeping, some simulation of related on-board systems needs to be present in these cases. To check out the initial simulator fully, some such simulation should be present in the initial simulator. It should not require greatly increased effort to insert the above generalized simulations rather than a simulation of a particular target vehicle. It should further vastly reduce the otherwise considerable effort required to update the simulator to an alternate target vehicle. Provision will be made to initialize each individual target vehicle simulation either upon release from the shuttle vehicle (or its payload manipulator), from shuttle (or manipulator) dynamics data, or at a preset time with a preset translational and rotational state vector. Provision will be made to terminate each individual target vehicle simulation as a function of

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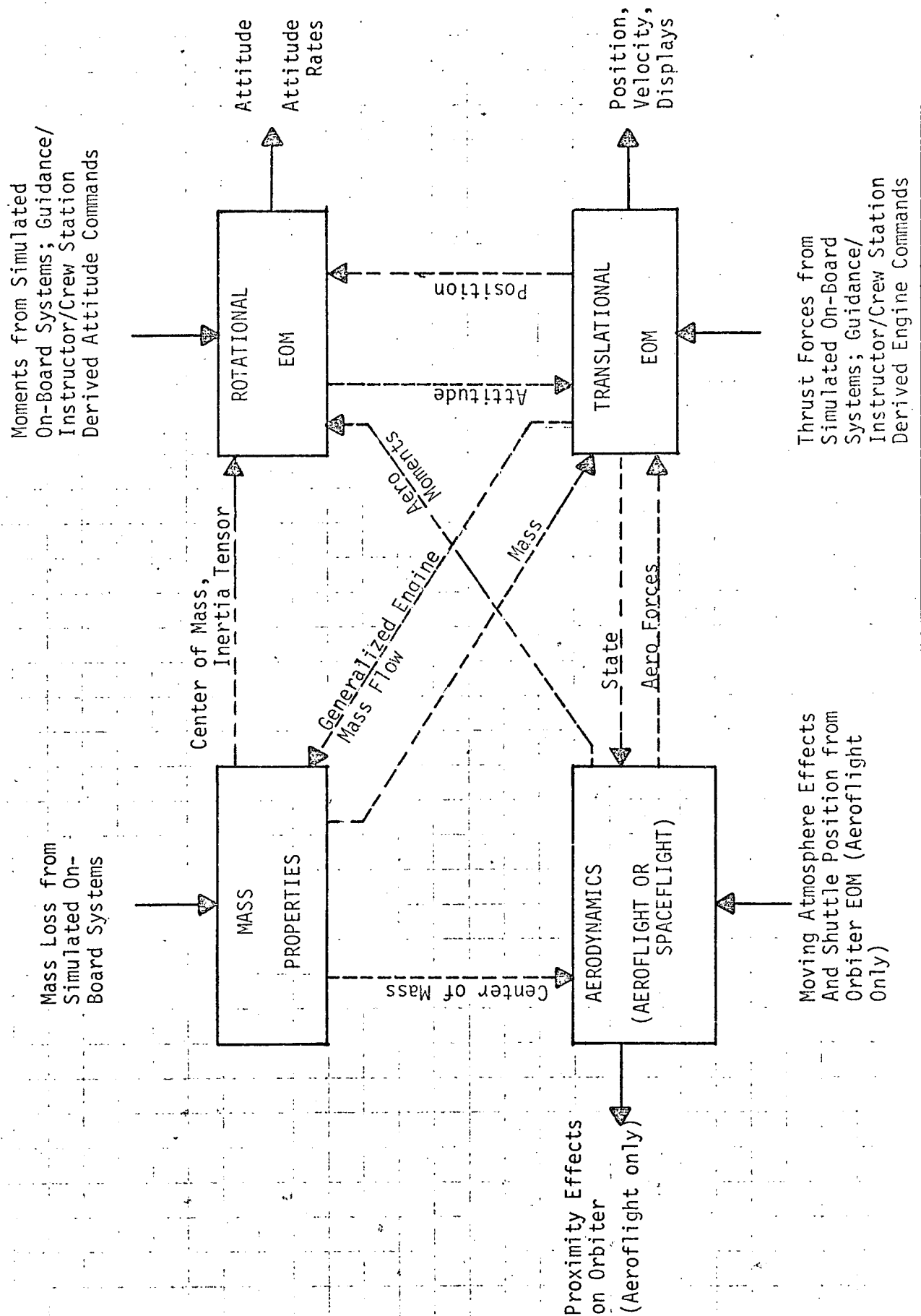
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distance from the shuttle vehicle, which distance may be different for each individual target vehicle. Provision will be made to permit two different termination distances for the external tank, one for dynamic pressure at separation less than 2 lb/ft^2 and the other for larger dynamic pressures. Termination distances and initialization option (and initial state and time for the preset initialization option) will be determined by reset terms. The conceptual design for target vehicle equations of motion has been subdivided into five subsystems, interrelated as shown below. For a given vehicle, either aeroflight aerodynamics or spaceflight aerodynamics will be executed, but not both. Aeroflight aerodynamics will be executed for SRM's and external tank, while spaceflight aerodynamics will be executed for all other target vehicles.



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3.3.8.2.1 Translational EOM and Propulsion

The simulated target vehicle translational equations of motion maintain target vehicle or payload c. m. positions and velocities when not attached to the shuttle vehicle or manipulator. Inputs to the equations of motion are thrust force, aerodynamic forces, docking mechanism forces, and vehicle mass. Vehicle mass is obtained from simulated target vehicle mass properties, and aerodynamic forces from simulated target vehicle aerodynamics. Thrust force may be obtained either from a specific target vehicle propulsion system simulation program or from a generalized approximate thrust simulation located within the translational EOM program. Any specific target vehicle propulsion system simulation program will be added later by modification (excepting boost SRM's and external tank), and will not form a part of the delivered simulator. The translational EOM program will, however, contain the necessary interface to permit addition of such a specific program without modification to translational EOM. The generalized thrust approximator will form a part of the initial simulator. A reset boolean will be provided to bypass the routine (it is bypassed if no translational propulsion system exists on a target vehicle, or if the propulsion system is simulated elsewhere in detail). Thrust and associated mass flow rate will be obtained by reset constants when the engine(s) fire, and will be zero at other times. Engine firing times and durations will be obtained from the simulated generalized target vehicle guidance, with instructor override provided. Thrust force from the generalized engine will always act along the body longitudinal axis and directly through the vehicle mass center. Body forces will be summed, transformed to the T system, and divided by mass to obtain accelerations. Two integration loops will be provided which calculate gravity and integrate total acceleration to obtain velocity and position. The loop in use at a given time is determined on the basis of the current magnitude of body acceleration. Above the threshold acceleration magnitude, the high-speed loop is used,

below it, the low-speed loop is used. The high-speed loop will be essentially the same as the non-orbit loop in shuttle translational EOM and the low-speed loop will be essentially the same as the orbit loop in shuttle translational EOM. The descriptions and explanations concerning these loops in section 3.3.8.1.1 apply here as well. A number of parameters are then generated for display purposes, including

- orbital elements
- shuttle - target vehicle range
- shuttle - target vehicle range rate
- target vehicle azimuth and elevation (from shuttle)

For atmospheric target vehicles (SRM's, external tank), a check will be made for recontact. For this purpose, the shuttle fuselage will be approximated as a rectangular solid, and wings and vertical stabilizer by infinitely thin planar surfaces. The target vehicle will be approximated as a cylindrical solid. Target vehicle translational state will be updated 10 times each second. During powered flight, this rate should provide adequate accuracy. During coasting orbital flight, the iteration rate of the extrapolation portion of the integration scheme has practically no influence on accuracy. This rate should, however, be adequate to prevent noticeable jumps in relative state. During step-ahead mode, the approach used for shuttle state advancement described in section 3.3.8.1.1 will also be used for target vehicle state advancement. The conceptual design for target vehicle translational EOM is sketched in figure 3.3.8.2.1-1.

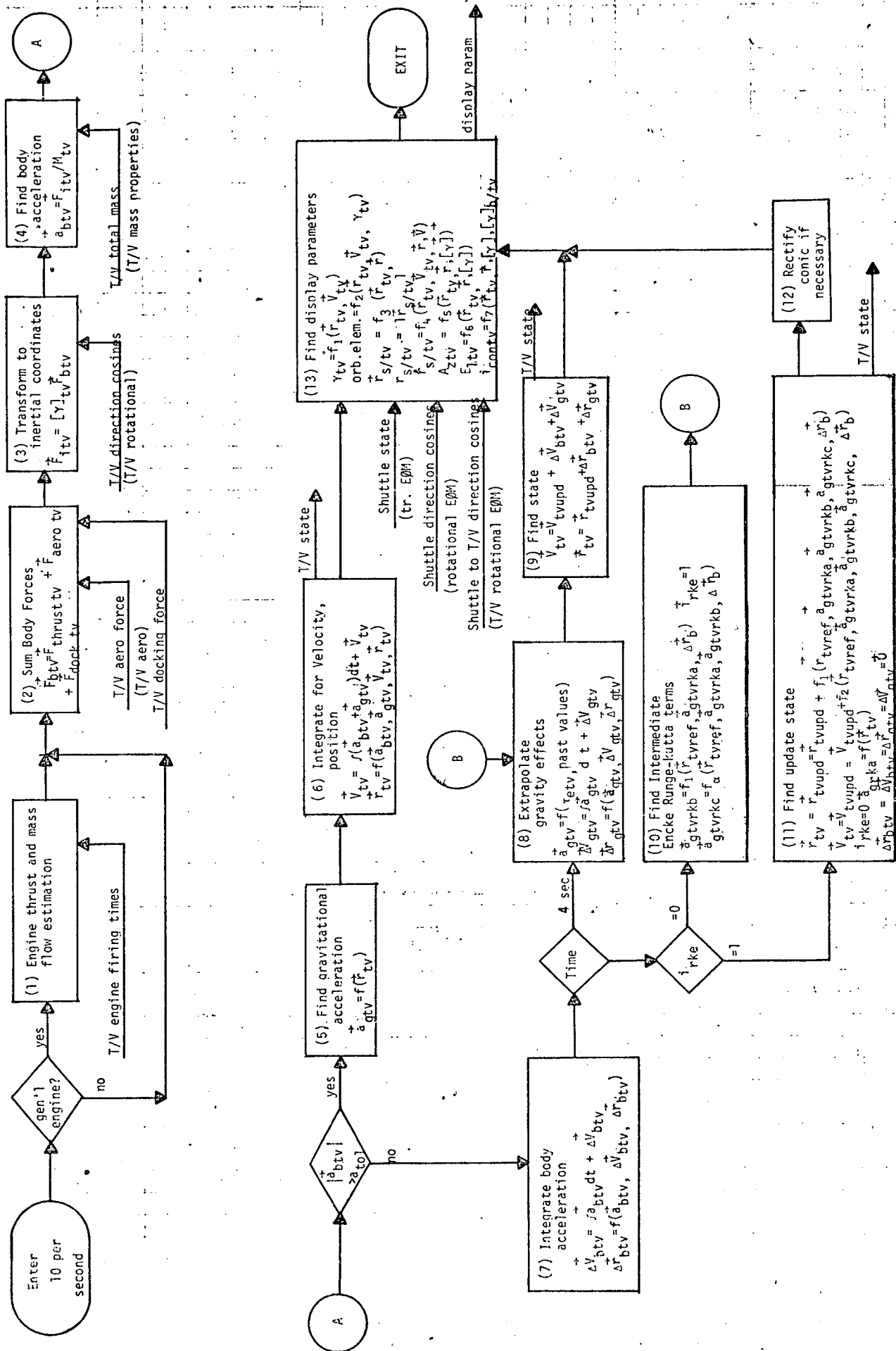


Figure 3.3.8.2-1

Symbol Dictionary for Figure 3.3.8.2.1-1

\vec{a}_{btv}	target vehicle body acceleration	\vec{r}_{tvref}	Encke reference position
\vec{a}_{gtv}	target vehicle gravitational acceleration	\vec{r}_{tvupd}	target vehicle position at last low speed loop update
\vec{a}_{gtvrka}	intermediate gravitational acceleration	$\dot{r}_{s/tv}$	target vehicle range rate
\vec{a}_{gtvrkb}	intermediate gravitational acceleration	\vec{v}	shuttle velocity
\vec{a}_{gtvrkc}	intermediate gravitational acceleration	\vec{v}_{tv}	target vehicle velocity
a_{tol}	low speed loop acceleration tolerance	\vec{v}_{tvupd}	target vehicle velocity at last low speed loop update
A_{ztv}	target vehicle azimuth with respect to shuttle body	γ_{tv}	target vehicle flight path angle
E_{ltv}	target vehicle elevation angle with respect to shuttle body	$[Y]$	shuttle attitude direction cosines
$\vec{F}_{aero_{tv}}$	aerodynamic force on target vehicle	$[Y]_{B/tv}$	shuttle body to target vehicle body direction cosines
\vec{F}_{btv}	total body force on target vehicle (TV body coordinate)	$[Y]_{tv}$	target vehicle attitude direction cosines
$\vec{F}_{dock_{tv}}$	docking force on target vehicle	$\Delta \vec{r}_{btv}$	delta position due to body acceleration since last update
\vec{F}_{itv}	total body force on target	$\Delta \vec{r}_{gtv}$	delta position due to gravitational acceleration since last update
$\vec{F}_{thrust_{tv}}$	thrust force on target vehicle	$\Delta \vec{v}_{btv}$	delta velocity due to body acceleration since last update
$i_{con_{tv}}$	flag indicating tv contact with shuttle vehicle	$\Delta \vec{v}_{gtv}$	delta velocity due to gravitational acceleration since last update
i_{RKE}	Runge-Kutta logic flag	T_{ETV}	time since last low speed loop update
M_{tv}	total target vehicle mass		
\vec{r}	shuttle position		
$r_{s/tv}$	target vehicle range		
$\vec{r}_{s/tv}$	vector from shuttle to target vehicle		
\vec{r}_{tv}	target vehicle position		

3.3.8.2.2 Rotational EOM and Attitude Control

The simulated target vehicle rotational equations of motion maintain target vehicle or payload attitudes and attitude rates when not attached to the shuttle vehicle or manipulator. Inputs to the equations of motion are attitude control moments, thrust moments, aerodynamic moments, moments exerted by the docking mechanism, and vehicle mass center and inertia properties. Mass center and inertia properties are obtained from simulated target vehicle mass properties, and aerodynamic moments from simulated target vehicle aerodynamics. Attitude control moments may be obtained either from a specific target vehicle control system simulation program, or from a generalized approximate control logic and thruster simulation located within the rotational EOM program. Any specific target vehicle control system simulation will be added later by modification, and will not form a part of the initial simulator. Target vehicle rotational EOM will, however, contain the necessary interface provisions to permit addition of such a specific program without modification to rotational EOM. The generalized approximate control logic and thruster simulation will form a part of the initial simulator. A reset boolean will be provided to bypass this routine (it is bypassed if no attitude control system exists on the vehicle or the attitude control system is simulated elsewhere in detail). Attitude commands will be obtained from simulated target vehicle guidance, the shuttle vehicle, or the instructor. Reset terms will be used to approximate the control phase plane logic. The phase plane will be assumed to be symmetric with respect to positive or negative rates, and identical for all three body axes. Up to five segments (linear or quadratic) may be used to define the upper deadband limits, and up to four may be used for the lower deadband limit. Up to five rate command regions may be defined in the upper region outside the deadband; up to two regions in the lower. Linear or quadratic segments may be used to separate these regions. The rate command in each region may be expressed as

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a first-order function of rate and position error. Only as many segments and regions as needed must be used. Segments bounding region and the deadband, as well as formulae for commanded rate change in each region will be defined by reset constants. Total reaction control moment about each axis will also be defined by reset constants. The above generalized phase plane logic will be capable of simulating the nominal shuttle orbiter phase plane; the only approximations required being of the formulae for the commanded rate changes in two of the seven firing regions. Target vehicles controlled by CMG's characteristically possess very slow attitude response. It is expected that any CMG controlled payloads will not exhibit substantial attitude change during the probably brief period in which they are in close visual contact with the shuttle. Their attitudes should remain inertially fixed. Thus, provision is made to bypass rotational EOM entirely for such payloads, providing an inertially fixed attitude. In a case in which better simulation is required, a modification can, of course, be readily added. Reaction control moments will be added to aerodynamic moments and thrust moments (from any special simulation - the generalized engine in translational EOM generates no torque). Gravity gradient moments will be calculated and included. Euler's equations will be solved to obtain angular accelerations, which will be integrated to obtain angular rates. Rates will be integrated to obtain direction cosines in a fashion similar to that described for shuttle vehicle rotational EOM in section 3.3.8.1.2. The direction cosine matrix will transform from the B coordinate system to the T coordinate system. Target vehicle rotational EOM will be updated 10 times each second. This should be adequate for purposes of crew perception, and is sufficient for interface with translational EOM. The conceptual design for target vehicle rotational EOM is sketched in figure 3.3.8.2.2.-1.

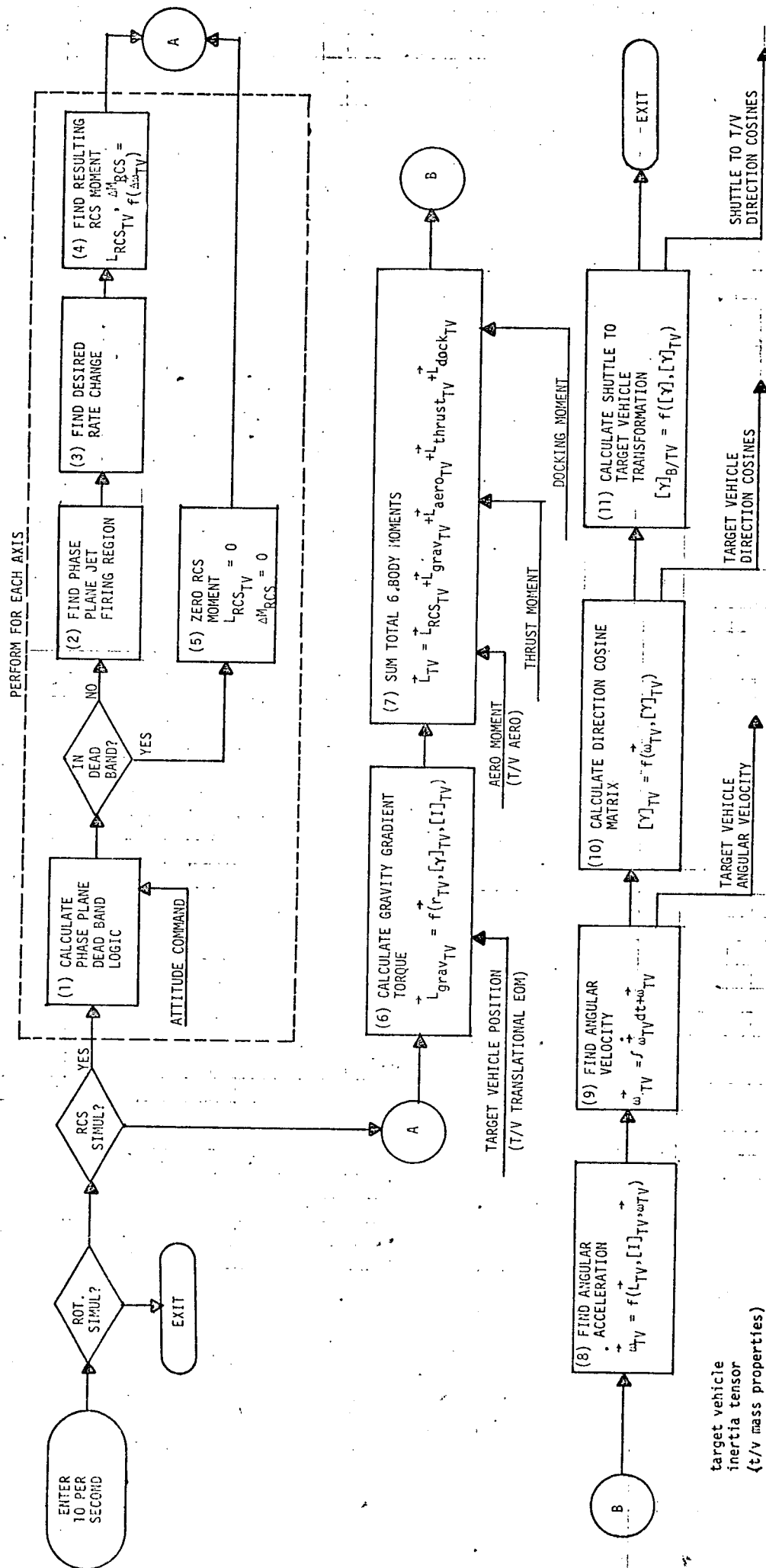


FIGURE 3.3.8.2.2-1

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Symbol Dictionary for Figure 3.3.8.2.2-1

$\vec{L}_{aero_{tv}}$	target vehicle aero moment
$\vec{L}_{dock_{tv}}$	target vehicle docking moment
$\vec{L}_{grav_{tv}}$	target vehicle gravity gradient
$\vec{L}_{RCS_{tv}}$	target vehicle RCS moment
$\vec{L}_{thrust_{tv}}$	target vehicle thrust moment
\vec{L}_{tv}	target vehicle total moment
\vec{r}_{tv}	target vehicle inertial position
$[\gamma]$	direction cosines, shuttle to inertial
$[\gamma]_{B/tv}$	direction cosines, shuttle to target
$[\gamma]_{tv}$	direction cosines, target to inertial
$\vec{\omega}_{tv}$	target vehicle angular velocity
$\dot{\vec{\omega}}_{tv}$	target vehicle angular acceleration
ΔM_{RCS}	mass loss due to RCS thrusting
$\Delta \vec{\omega}_{tv}$	desired target vehicle rate change

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3.3.8.2.3 Mass Properties

Many target vehicles will not require a dynamic real-time mass properties simulation. Over the interval of interest, changes in mass properties will be negligible. Other target vehicles, e.g. those with propulsive stages, will demonstrate significant changes in mass properties. Thus, reset booleans will be provided which will allow dynamic mass property simulation to be bypassed for certain target vehicles. Certain other target vehicles (e.g., SRM's external tank) will have their mass properties calculated elsewhere (in the cases of SRM's or external tank, in the appropriate on-board system simulation programs). Thus, in those cases also, the target vehicle mass properties simulation is bypassed. In those cases in which the simulation is not bypassed, inputs to the simulation are engine mass flow and reaction control system mass flow. Total mass is decremented accordingly. Provision will be made to permit interpolation on mass to obtain target vehicle center of mass and tensor of inertia. Obtaining mass center and inertia tensor as functions of mass has been used previously on the CMS booster simulation, and has provided acceptable accuracy. Similar accuracy standards should be acceptable for almost all target vehicle simulation. An interpolation approach will also be relatively easy to update to a different target vehicle. An iteration rate of twice per second is estimated, under fairly conservative rocket assumptions, to require a 1/2 second overburn to erase resulting error on a $7000 \frac{\text{ft}}{\text{sec}} \Delta V$ burn, which should be quite acceptable in terms of ability of the crew or ground to notice. Mass distribution parameters could probably be iterated even more slowly, if time is critical. The conceptual design is sketched in figure 3.3.8.2.3-1.

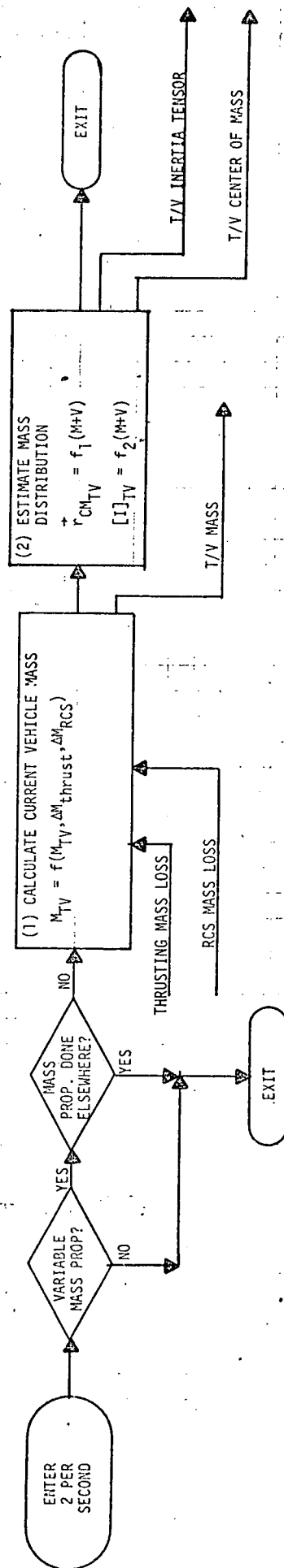


FIGURE 3.3.8.2.3.-1

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Symbol Dictionary for Figure 3.3.8.2.3-1

 $[I]_{tv}$ target vehicle
inertia tensor ΔM_{RCS} mass loss due to target
vehicle RCS thrusting M_{tv} target vehicle
total mass ΔM_{thrust} mass loss due to target
vehicle engine firing \vec{r}_{cm} target vehicle mass
center location (T/V
body axes)

3.3.8.2.4 Aeroflight Aerodynamics

The simulated target vehicle aeroflight aerodynamics calculates aerodynamic forces and moments on detached target vehicles operating within the atmosphere, (namely boost SRM's and external tank) and proximity atmospheric effects upon both shuttle vehicle and target vehicle. Inputs to simulated aeroflight aerodynamics include target vehicle position, velocity, and attitude (target vehicle translation EOM), target vehicle attitude direction cosines (target vehicle rotational EOM), target vehicle center of mass (target vehicle mass properties) wind and rough air effects (shuttle aerodynamics), shuttle position (shuttle translational EOM), and shuttle attitude direction cosines (shuttle rotational EOM). Velocity of the target vehicle with respect to the moving atmosphere is calculated in the target vehicle body-fixed coordinate system using the same wind and rough air effects which are included in shuttle aerodynamics. Speed of sound and atmospheric density are obtained from the same median profiles used by shuttle aerodynamics as functions of altitude only. Proximity effects will be calculated as functions of mach number and target vehicle displacement for both vehicles. Aerodynamic forces and moments are computed in the target vehicle body fixed coordinate system. Proximity effects will be included with isolated body characteristics by multiplicative and additive factors to obtain total forces and moments. Definition of parameters upon which aerodynamic coefficients will depend and the mode of calculation of moments was generally obtained from existing incomplete data. As additional data appears, parameter dependencies below should be reviewed and revised accordingly. An iteration rate of 10 per second should prove adequate for simulation of proximity effects, and other accuracy requirements are much lower. The conceptual design is sketched in figure 3.3.8.2.4-1.

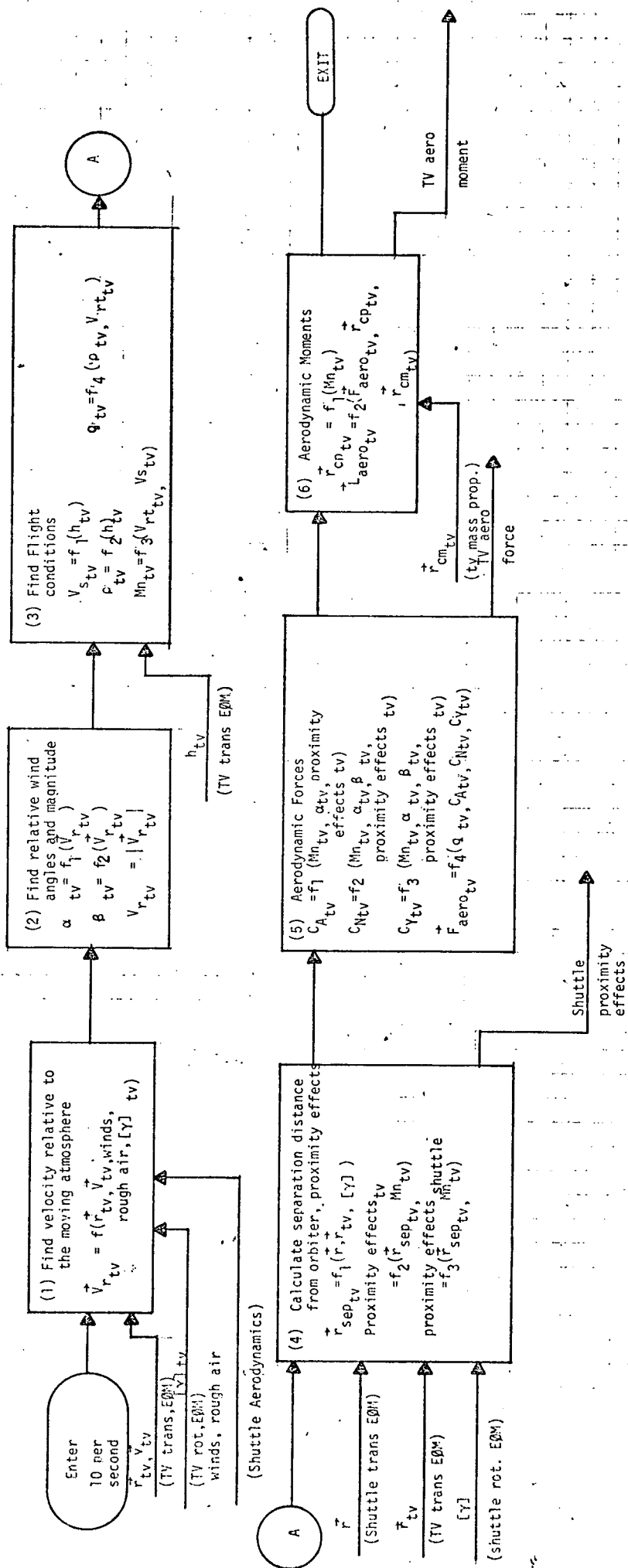


FIGURE 3.3.8.2.4-1

Symbol Dictionary for Figure 3.3.8.2.4-1

 $C_{A_{tv}}$ target vehicle axial
force coefficient $C_{N_{tv}}$ target vehicle normal
force coefficient $C_{l_{tv}}$ target vehicle side
force coefficient $\vec{F}_{aero_{tv}}$ target vehicle
aerodynamic force h_{tv} target vehicle altitude $\vec{L}_{aero_{tv}}$ target vehicle
aerodynamic moment Mn_{tv} target vehicle
mach number q_{tv} target vehicle
dynamic pressure \vec{r} shuttle position $\vec{r}_{cm_{tv}}$ target vehicle c.m.
location $\vec{r}_{cp_{tv}}$ target vehicle center
of pressure position \vec{r}_{tv} target vehicle position \vec{V}_{rtv} target vehicle velocity
with respect to moving
atmosphere V_{stv} target vehicle speed
of sound \vec{V}_{tv} target vehicle velocity α_{tv} target vehicle angle
of attack β_{tv} target vehicle sideslip angle $[\gamma]$ shuttle vehicle
direction cosines $[\gamma]_{tv}$ target vehicle
direction cosines ρ_{tv} target vehicle
atmospheric density

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3.3.8.2.5 Spaceflight Aerodynamics

The simulated target vehicle spaceflight aerodynamics calculates aerodynamic forces and moments on detached spaceflight target vehicles (all target vehicles except boost SRM's and external tank). Inputs to simulated spaceflight aerodynamics include target vehicle position, velocity, and altitude (target vehicle translational EOM); and target vehicle attitude direction cosines (target vehicle rotational EOM). Velocity of the target vehicle with respect to the atmosphere is calculated in the target vehicle body-fixed coordinate system, assuming an atmosphere rotating uniformly with the earth. Atmospheric density is obtained from the same median profile used by shuttle aerodynamics as a function of altitude alone. Definition of parameters upon which aerodynamic coefficients will depend was generally obtained from existing incomplete data. As additional data appears, parameter dependencies below should be reviewed and revised accordingly. An iteration rate of twice per second is chosen to match that of orbital shuttle aero. It can be justified for the reasons given in section 3.3.8.1.4. The conceptual design is sketched in figure 3.3.8.2.5.-1.

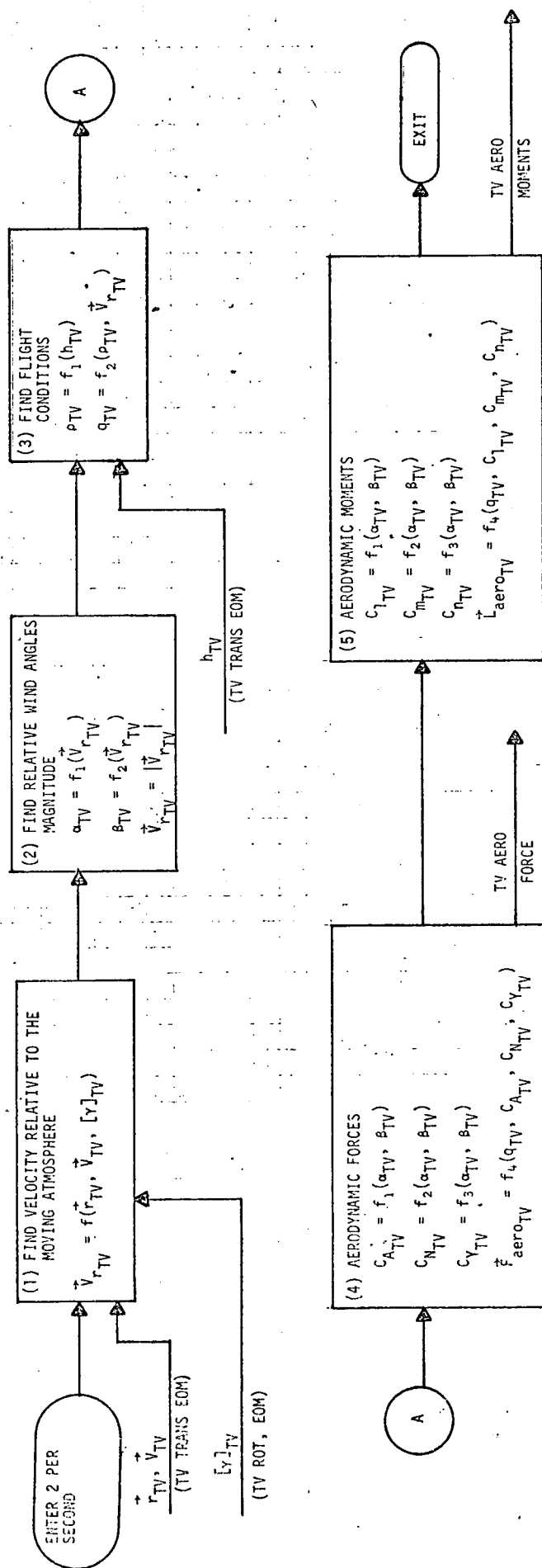


FIG. 3.3.8.2.5.-1

Symbol Dictionary for Figure 3.3.8.2.5.-1

 $C_{A_{tv}}$ target vehicle axial
force coefficient $C_{\ell_{tv}}$ target vehicle rolling
moment coefficient $C_{m_{tv}}$ target vehicle pitching
moment coefficient $C_{n_{tv}}$ target vehicle yawing
moment coefficient $C_{N_{tv}}$ target vehicle normal
force coefficient $C_{Y_{tv}}$ target vehicle side
force coefficient $\vec{F}_{aero_{tv}}$ target vehicle aerodynamic
force h_{tv} target vehicle altitude $\vec{L}_{aero_{tv}}$ target vehicle aerodynamic
moment q_{tv} target vehicle dynamic
pressure \vec{r}_{tv} target vehicle position $\vec{V}_{r_{tv}}$ target vehicle velocity
with respect to moving
atmosphere \vec{V}_{tv} target vehicle velocity α_{tv} target vehicle angle
of attack β_{tv} target vehicle sideslip angle $[Y]_{tv}$ target vehicle direction
cosines ρ_{tv} target vehicle atmospheric
density

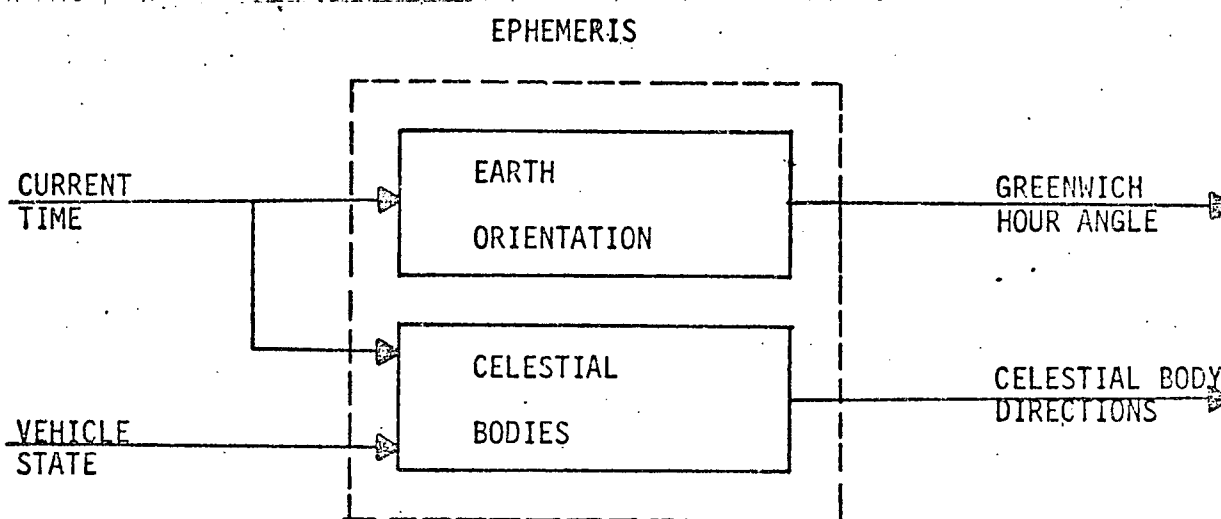
3.3.8.3 Ephemeris

The real-time ephemeris program must perform two functions:

determine earth orientation

determine directions of celestial bodies

at any point in time during the mission. Accordingly, the real-time ephemeris program may be functionally conceived as follows:



3.3.8.3.1 Earth Orientation

The precession and nutation of the earth's equator and the rotation of the earth about its polar axis determine the orientation of the earth in inertial space. Over a period of seven days, reorientation of the equator due to precession and nutation are not significant (less than two arc-seconds in any axis). Thus, it will be assumed that the equinox and spin axis remain inertially fixed over that period. The earth's spin may be described by the True Greenwich Hour Angle, which is the angle from the true vernal equinox to the intersection of the Greenwich Meridian and the Equator. To achieve the required accuracy of ± 2 arc-seconds, without perceptible jitter, the Hour Angle will be updated ten times per second. The Earth's axial rotation rate

is about $15 \frac{\text{arc-sec}}{\text{sec}}$. Thus, at this iteration rate, the Hour Angle is always maintained within ± 1.5 arc-sec., which is equivalent to about 150 feet (ground-track) at the equator. No formal calculation of an earth-fixed to inertial coordinate transformation matrix will be performed. As the T coordinate system is used for the inertial system and the E coordinate system is used for the earth-fixed system, this transformation consists solely of a rotation through the Hour Angle. This can be most efficiently accomplished by an angle rotation rather than a matrix multiplication. Hence, the sine and cosine of the Hour Angle are maintained rather than a transformation matrix. The conceptual design is presented in figure 3.3.8.3-1.

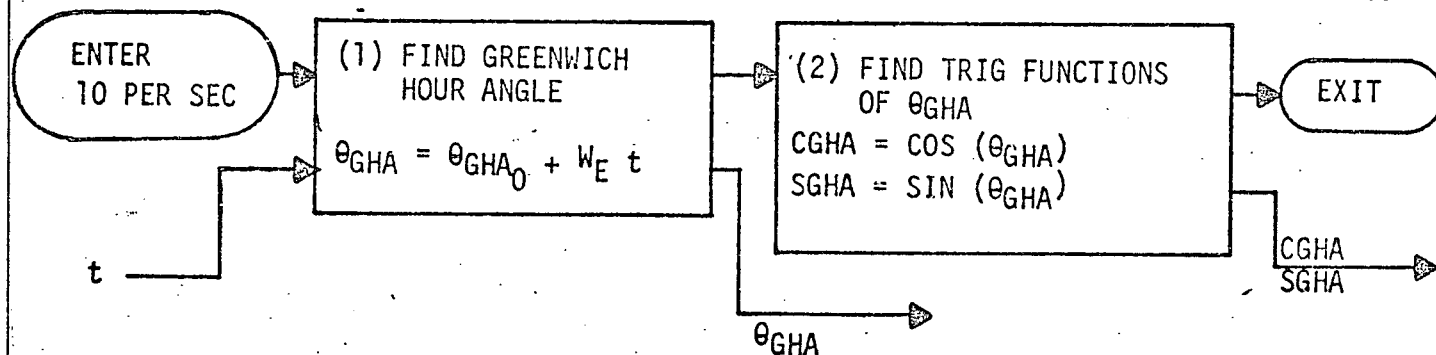


Figure 3.3.8.3-1

Symbol Dictionary for Figure 3.3.8.3-1CGHA cosine of θ_{GHA} θ_{GHA} True Greenwich Hour AngleSGHA sine of θ_{GHA} θ_{GHA_0} True Greenwich Hour Angle at
liftoff (reset constant)

t elapsed time since liftoff

 ω_E Hour Angle rate (reset constant)

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If it is desirable to save time at the expense of core, numerous time-consuming calculations of the exact trig functions of θ_{GHA} can be avoided. The exact trig functions can be calculated only once every five seconds, while CGHA and SGHA are updated in the interim using the following approximations:

$$\sin(\theta + \Delta\theta) \approx \sin \theta + (\Delta\theta) \cos \theta$$

$$\cos(\theta + \Delta\theta) \approx \cos \theta - (\Delta\theta) \sin \theta$$

This procedure will not create errors exceeding 2×10^{-9} in the trig functions, which is quite acceptable.

3.3.8.3.2 Celestial Bodies

The inertial directions (from the vehicle) of the following celestial bodies will be maintained:

Sun (also solar occlusion will be calculated)

Moon

Planets (Mercury, Venus, Mars, Jupiter, Saturn)

Stars (detectable by star tracker)

Planetary, lunar and solar directions will take into account both the changing true directions of the other celestial bodies with respect to the earth, and the position of the vehicle with respect to the earth. Relative motion of sun, stars, ecliptic plane and equatorial plane are negligible over the duration of a mission, compared to the tolerances specified in the requirements. They will be ignored. Stellar parrallax is negligible (less than ± 1 arc-second). Thus, true directions of the stars will be provided in a table of reset constants. Aberration effects can reach 25 arc-seconds for solar, planetary, and stellar observations, so they must be included. Lunar aberration is much less (about 5 arc-sec maximum) and can be ignored. The program will calculate the apparent positions of sun and

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planets only. Since apparent position of only a few particular stars must be known at any given time, it is more efficient to perform aberration corrections in the using programs (e.g., star tracker) for just those stars required. The ephemeris will, however, provide certain generalized terms used in the calculation of stellar aberration. True earth-referenced positions and velocities (velocities are required for aberration correction) of sun, moon, and planets will be obtained in real-time by interpolation on pre-stored tables. Jet Propulsion Laboratory (JPL) Ephemeris tapes will serve as the source for the pre-stored tables. JPL tapes contain data up to the year 2000. The reset generator program will scan the JPL tape, and strip and condition appropriate blocks of data for use by the real-time program. Time tags will be changed to reflect mission elapsed time. Interpolation will be done using an Everett's interpolation scheme. All directions will be output in the appropriate T coordinate system. Since JPL data (and probably star data) will be in the S coordinate system, the reset generator will reform the necessary transformation to place it in the T coordinate system. To remain safely within tolerances specified in the requirements, the following minimum iteration rates are desirable:

Moon	once per 5 seconds
Mercury	once per 45 seconds
Venus	once per 75 seconds
Mars	once per 1-3/4 minutes
Jupiter	once per 3-1/2 minutes
Sun	once per 5 minutes
Saturn	once per 7 minutes
Stars	once per 15 minutes

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While a slower iteration rate than once per five seconds is feasible for all bodies except the moon, it is questionable whether the amount of time saved would justify the ensuing conceptual complication (or small additional core requirement). Since orbital sunrise requires about eight seconds, such an update rate for solar occlusion should be acceptable. The resulting conceptual design is sketched in figure 3.3.8.3-2.

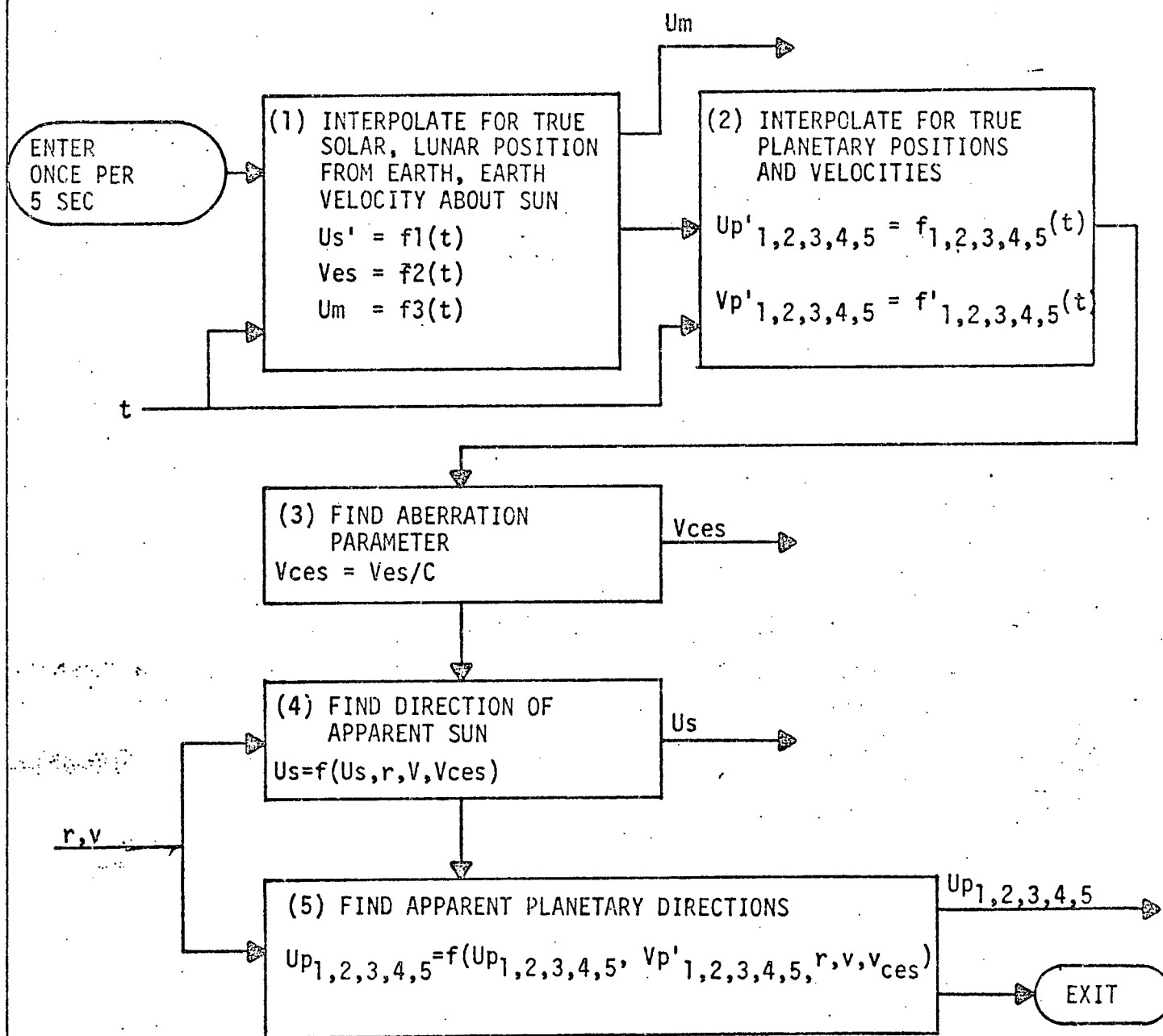


Figure 3.3.8.3-2

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Symbol Dictionary for Figure 3.3.8.3-2

C	speed of light (constant)	U_s	unit vector in apparent direction of sun
N_{so}	boolean indicating solar occultation vehicle position (T system)	U_s	true position of sun
t	elapsed time since liftoff	V	vehicle inertial velocity (T system)
U_m	unit vector in direction of moon	V_{ces}	$\frac{1}{c} (V_{es})$
$U_{p1,2,3,4,5}$	unit vector in apparent direction of planet	V_{es}	velocity of earth about sun
$U_{p1,2,3,4,5}$	true position of planet	$V_{p1,2,3,4,5}$	velocity of planet

3.3.9 Thermal System

The Thermal System is divided into three major subsystems: Thermal Protection (TPS), Thermal Control (TCS) and Environmental and Life Support (ECLSS).

Throughout the Thermal System Simulation, the laws of conservation of mass and energy will be applied. For example, heat exchangers and coldplates will transfer heat to the coolant medium (water, freon, etc.) according to:

$$\Delta T_1 = \frac{\dot{Q}_{in}}{\dot{W}_1 C_{p1}}$$

where: ΔT_1 = outlet temperature minus inlet temperature

\dot{Q}_{in} = heat transfer rate into coolant

\dot{W}_1 = flow rate of the coolant

C_{p1} = specific heat of the coolant

Then the temperature change across heat generating (absorbing) components can be given as:

$$T_{out} = T_{in} + (\Delta T_1)(K)$$

where: T_{out} = coolant outlet temperature

T_{in} = coolant inlet temperature

K = iteration rate (executions/unit time)

The calculations for the heat transfer rate, \dot{Q}_{in} , will account for coolant properties, physical dimensions and flow characteristics:

$$\dot{Q}_{in} = f(D_1, \dot{W}_1, C_{p1}, K_1, \Delta T_2, \Delta X_1, K_2, A_1)$$

where: D_1 = effective diameter of coolant passage

K_1 = thermal conductivity of coolant

ΔT_2 = temperature difference, coolant to component.

ΔX_1 = effective conduction thickness

K_2 = thermal conductivity of component material

A_1 = area of heat flux

Radiation heat transfer calculations will be derived from the general equation:

$$\dot{Q}_{em} = f(\epsilon, \sigma, T_1^4)$$

where \dot{Q}_{em} = heat transfer rate due to radiation

ϵ = emissivity of the radiative surface

γ = Stefan-Boltzmann constant

T_1 = surface temperature

This basic equation will be modified for specific applications to consider surface areas and geometric configuration. For exterior vehicle calculations, solar radiation and radiation emitted and reflected from the earth will be included as well as shadowing effects where they apply.

The net result of heat fluxes into and out of a given volume of any material, solid, liquid or gas will be calculated by the equation:

$$\dot{Q} = f[\Sigma(\dot{Q}_{RAD} + \dot{Q}_{COND} + \dot{Q}_{CONV})]$$

where: \dot{Q} = net heat transfer rate

\dot{Q}_{RAD} = heat transfer due to radiation

\dot{Q}_{COND} = heat transfer rate due to conduction

\dot{Q}_{CONV} = heat transfer rate due to convection

The net heat transfer rate is then integrated against the total

heat content:

$$Q = Q_{n-1} + (\dot{Q})(K)$$

where: Q = total heat content

Q_{n-1} = initial total heat content

And then a new temperature is computed from:

$$T_2 = \frac{Q}{M_1 C_{p2}}$$

where: T_2 = bulk temperature of material

M_1 = mass of the material

C_{p2} = specific heat of the material

Flow rates of compressible fluids will be computed based on differential pressure relationships. In general, the form is:

$$\dot{W}_2 = f(\Delta P_1, D_2)$$

where: \dot{W}_2 = the calculated mass flow rate.

ΔP_1 = the pressure differential existing across opening or orifice.

D_2 = effective diameter of the opening or orifice.

In each case, conservation of mass will apply to account for the flow rate. For example, the volume which receives flow rate \dot{W}_2 will have its mass increased by:

$$M_2 = M_{2n-1} + (\dot{W}_2)(K)$$

where: M_2 = mass of gas within the volume

M_{2n-1} = initial mass of gas

From this mass calculation, a new pressure may be calculated for use in the next pressure differential calculation:

$$P_1 = f(V_1, M_2, R_1, T_2)$$

where: P_1 = pressure of gas

V_1 = volume containing M_2

R_1 = gas constant for the particular gas

T_2 = bulk temperature of the gas

The ideal gas law, $PV = MRT$, can be used for all compressible gas calculations except at very high pressures and for cryogenic.

Empirical equations of state will be used in these cases.

3.3.9.1 Thermal Protection Subsystem

The Thermal Protection Subsystem (TPS) is intended to thermally shield the vehicle from high temperatures during atmospheric flight. Two basic arrangements are planned, one for high temperatures (up to 2500°F) on the leading and lower surfaces of the exterior and one for moderate temperatures (below 650° F) for the upper surfaces.

The simulation will cover both atmospheric and orbital flight cases. A critical altitude will be used to determine which case is dominant, i.e., aerodynamic heating from atmospheric flight or radiative effects encountered in orbital flight.

For the simulation, the exterior vehicle surface will be divided into a number of sections so that heat fluxes and temperatures at various points can be calculated.

3.3.9.1.1 Radiation

Radiation from the following sources will be accounted for in the

- simulation:
1. Solar
 2. Earth emission
 3. Solar, reflected from earth
 4. Deep space

A constant solar heat flux will be used since the orbital distances are small compared to the distance from earth to the sun. For a given section of area, orientation relative to the sun-earth line will be used to determine the effective area. Figure 3.3.9.1.1.1 shows a typical planar area segment or panel,

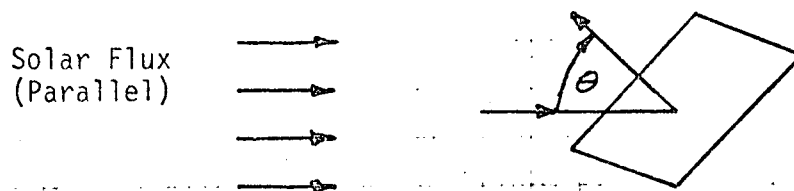


Figure 3.3.9.1.1.1

If the actual surface area is A_2 , then correcting for the effective area w.r.t. solar flux, the solar radiation impingement is given

by: $\dot{Q}_{sr} = f(A_1, \theta, C_1, \alpha_1)$

or specifically:

$$\dot{Q}_{sr} = (\alpha_1)(C_1)(A_2)(\cos\theta)$$

where: \dot{Q}_{sr} = heat transfer to panel due to solar radiation

C_1 = constant for solar heat flux

A_2 = actual area of panel

α_1 = absorptivity of panel surface

The effects due to the earth's reflection of solar radiation will also employ a constant, determined experimentally, with corrections made for vehicle position relative to the earth-sun line and for orientation relative to the earth-vehicle line. Figure 3.3.9.1.1.2 shows an example.

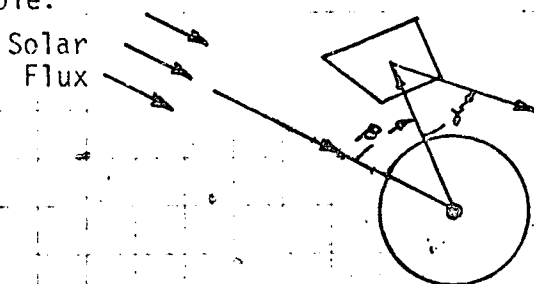


Figure 3.3.9.1.1.2

Again using a planar area segment, the reflected flux will be calculated by: $F_{ref} = f(C_2, \beta)$

or,

$$F_{ref} = (C_2)(\cos \beta)$$

where: F_{ref} = flux reflected at β

C_2 = constant reflected flux at $\beta=0$

β = angle between the sun-earth line and the earth-vehicle line

Of this reflected flux, only a portion will strike the panel. If the panel is oriented away from the earth-vehicle line by an angle γ , then the heat transferred to the panel will be:

$$Q_{er} = (F_{ref})(A_3)(\cos \gamma)$$

where: Q_{er} = heat transfer to panel due to reflected solar radiation

A_3 = actual area of the panel

Both direct and reflected solar radiation will be ignored when the vehicle is in the umbra.

Emission from the earth however will be experienced in and out of the umbra and will be simulated as a constant flux corrected for orientation to the earth-vehicle line.

Another significant heat flux is that radiated away from the exterior surfaces to deep space. In general, the solution will be of the form given in 3.3.9 in the general discussion.

The total heat transfer to a typical elemental section of surface then can be determined by summing all of the above separate components.

$$\dot{Q}_{rad} = \dot{Q}_{sr} + \dot{Q}_{er} + \dot{Q}_{ee} - \dot{Q}_{em}$$

where: \dot{Q}_{ee} = heat transfer due to earth emission

Parameters defining vehicle position and orientation will be utilized to permit dynamic computations for radiation.

3.3.9.1.2 Aerodynamic Effects

Below a critical altitude, the radiation heat transfer is negligible compared to aerodynamic effects. In the simulation, only one or the other will be computed at a given time. Based on test data, an empirical relationship can be developed to determine heat transfer due to aerodynamic heating. The relationship will be based on vehicle velocity, and atmospheric density.

$$Q_a = f(q, v, \alpha_2, A_3)$$

where: Q_a = heat transfer due to aero

q = dynamic pressure

v = velocity

α_2 = angle of attack

A_3 = surface area of section

Actual test data will be used to generate curve fit equations. Again, the outer surface will be divided into sections, with a different equation applicable to each.

Figure 3.3.9.1.2 shows a group of sections schematically and provides a simplified picture of the method to be used to calculate the temperature of a given section.

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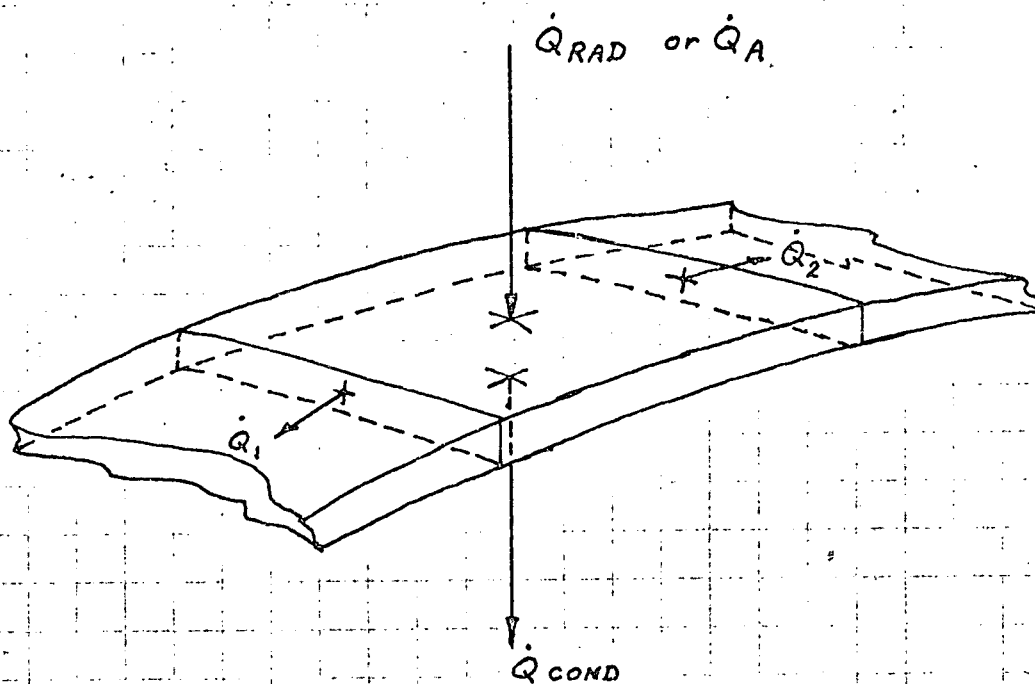


FIGURE 3.3.9.1.2

In this example it can be seen that in addition to the heat transfer already discussed, conduction to neighboring sections, Q1 and Q2 will be simulated. All heat transferred into and out of a given section will be summed and its influence on the temperature of the section will be calculated as shown in the general discussion. The TPS equations will be calculated once per second.

3.3.9.2 Thermal Control Subsystem

This subsystem (TCS) consists mainly of passive elements such as heat sinks, surface coatings and insulators. The subsystem simulation will consist mainly of conduction heat transfer equations. The basic equation is given by:

$$\dot{Q}_{COND} = (K_3)(A_4)\left(\frac{\Delta T_3}{\Delta X_2}\right)$$

where: K_3 = thermal conductivity of material

A_4 = area normal to heat flux

ΔT_3 = temperature differential of two neighboring sections

ΔX_2 = distance between the effective centers of neighboring sections.

The conduction equations will be applied to each layer of insulation material until the cabin walls are reached. At this point, the Environmental Control and Life Support Subsystems will accept the heat flux and determine the influence on the internal walls and cabin atmosphere temperatures. The TCS equations will be executed at a 1/second rate.

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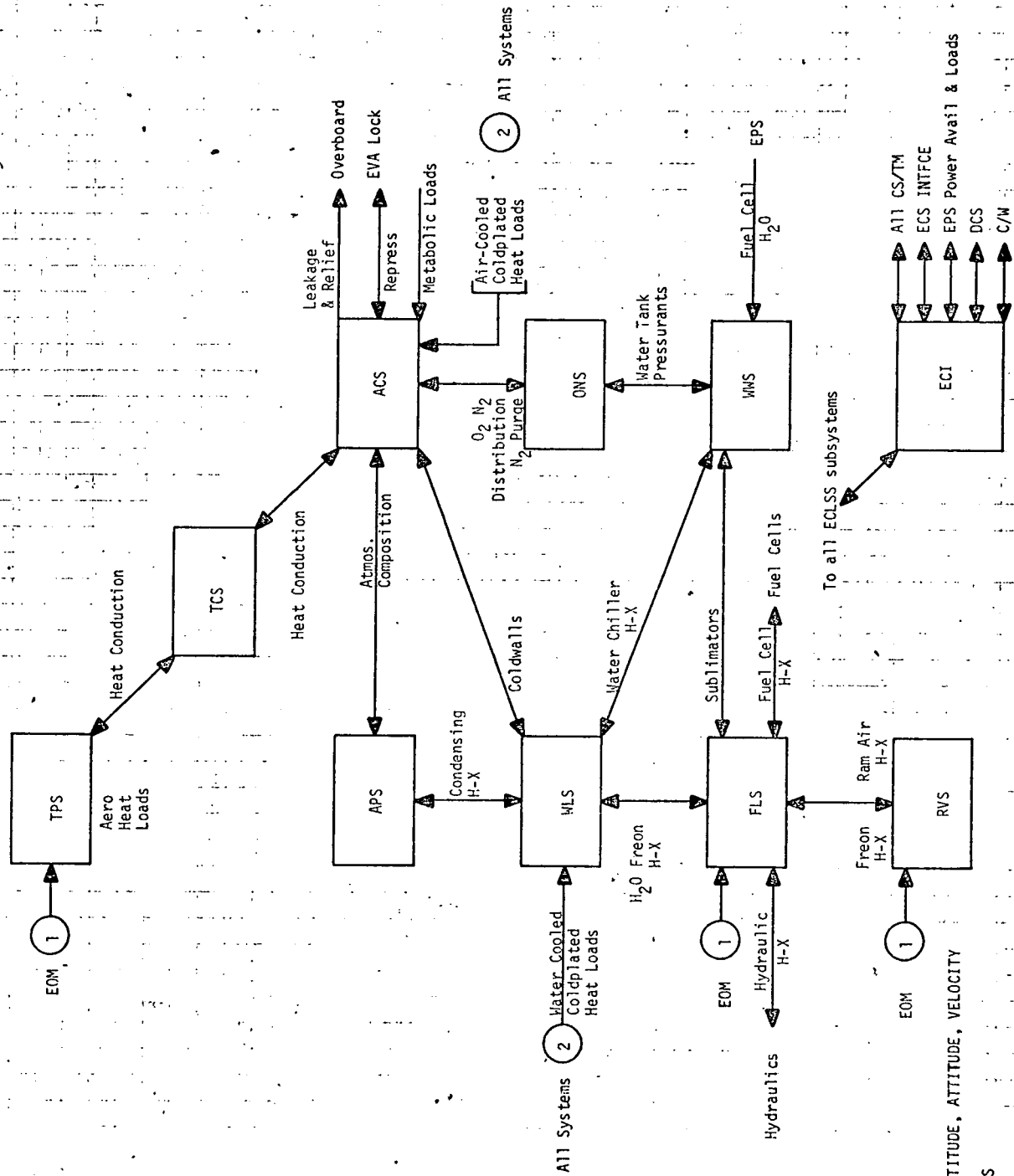
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3.3.9.3 Environmental Control and Life Support Subsystem

The Environmental Control and Life Support System (ECLSS) simulation will be divided into eight subsystems. Figure 3.3.9.3 shows the principal organization of the subsystems and the basic interface areas. In each case, a written description adjacent to a block indicates that a common item will be simulated in that block. The TPS and TCS are also shown in the figure.

Figure 3.3.9.3



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The ECLSS subsystems will receive crew station switch and digital control commands via the ECLSS interface program (ECI). An iteration rate of 5/second permits momentary switches and digital commands to be read at a satisfactory speed. The program also generates output parameters for crew station meters and lights, telemetry, bus loads and caution and warning. Portions of the program will be executed at a slower rate, 1/second.

The other ECLSS subsystems will contain the equations necessary to accurately simulate the real-world components and equipment. Each subsystem will interface with non-ECLSS subsystems as shown in Figure 3.3.9.3.

The atmosphere circulation subsystem (ACS) will consist of calculations for the cabin, payload compartment, airlock and avionics bay atmospheres. Temperatures, pressures and partial pressures of specific gases will be accounted for. Internal wall heat loads, metabolic heat loads, and air cooled coldplated equipment heat loads will be calculated. Fire detection and provisions for a high nitrogen purge of the avionics bay will be calculated. Calculations for EVA lock pressurization as well as nominal cabin gas leakage and overboard relief valves will be included. An iteration rate of 5/second will be used in order to stabilize the flow rate as a function of the differential pressure between compartments.

The atmosphere purification subsystem (APS) contains the simulation for the condensing heat exchangers, carbon dioxide removal and cabin fans. This subsystem will interface with ACS regarding the composition of the cabin atmosphere. The heat transfer in the condensing heat exchangers will be calculated in this program. A 2/second iteration rate will be used.

The water loop subsystem (WLS) will contain the equations for pumps, loop flow rates and pressures, cabin coldwalls (whose convective effects will be simulated in the ACS), water cooled coldplated equipment, the avionics bay heat exchanger, the water/freon heat exchanger and the water chiller heat exchanger. Iterations at 1/second will be used.

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The freon loop subsystem (FLS) will provide for the simulation of pumps, loop flow rates and pressures, the fuel cell heat-exchanger, the hydraulic heat exchanger, the radiators, the sublimators and the payload heat exchanger. The GSE heat exchanger does not require simulation. The discussion given in 3.3.9.1.1 describing radiation calculations will also apply to the radiators in the FLS. The FLS will perform the heat transfer calculations for the fuel cell and hydraulics programs. Altitude, attitude and velocity will be used to determine radiator performance. The program will be calculated at a 1/second rate.

The oxygen/nitrogen subsystem (ONS) will be simulated in detail. All supply tanks, manifolds, valves, regulators and two gas controls will be included. This subsystem provides either oxygen or nitrogen to ACS as required by the two gas controller logic. Nitrogen pressurant is also provided to the waste/water subsystem water tanks. All calculations for the water tank pressures as a function of nitrogen pressurant will be performed in the ONS. A calculation rate of 2/second will be used.

The waste/water subsystem (WWS) will compute the accumulation and disposal of waste and potable water. The masses and temperatures in each tank will be computed in this program. Excess water from the fuel cells will be added to the potable H₂O tank. Water from this tank will be sent to the FLS where the sublimator equations are located. The waste tank will accumulate condensate from the APS condensing heat exchanger calculations. A 1/second iteration rate is adequate for the WWS simulation.

The ram vapor subsystem (RVS) will contain all calculations required for the vapor cycle coolant loop. Included in this loop are the ram air heat exchanger, the freon heat exchanger, compressor and expansion valve. Altitude, attitude, and velocity will be primary inputs for the ram air heat exchanger calculations. These calculations will be ignored at extremely high altitudes where the air density is negligible. This program will be executed at a 2/second rate.

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3.3.10 Payload Accommodation System

The simulator payload accommodation system will simulate the operation of the payload manipulator arms, payload attachment devices, payload bay doors, and the payload bay lighting and television subsystems. The simulated payload accommodation system will receive inputs from the simulated equations of motion (shuttle and target vehicle state, target vehicle mass properties), the electrical power subsystem (power availability), the hydraulic power subsystem (power availability), the crew station, and the instructor station (malfunctions, biases, etc.). Information will be provided on payload attachment status, arm dynamics, payload door position; light, camera, and monitor operation; electrical power loadings, and hydraulic flow. The basic configuration and data interchnage of the simulated payload accommodation system is illustrated below.

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3.3.10.1 Payload Attachment Subsystem

The simulated payload attachment subsystem simulates the operation and effects of the real-world subsystem of the same name. The simulated payload attachment is iterated once for each applicable payload. If the payload is detached, forces (if any) exerted upon the payload by the attachment fitting payload trunnion guides will be calculated for proper dynamics simulation. Account will be taken of payload motion as well as payload position in calculation of such forces, to ameliorate effects of sampling lag. Attach commands will be honored only if switch and breaker settings are proper and power is available. A payload will be attached when the command is issued, and position and velocity of payload attachment points with respect to shuttle retention points is within the applicable constraints. When a payload has just been attached, its mass center position and inertia tensor with respect to shuttle body coordinates will be calculated for use in the calculation of mass properties. An attached payload will be checked for a release command. A release command will exist when switch and breaker settings are proper and power is available. At the point at which a payload is released, its state for target vehicle EOM will be initialized using shuttle state and retention state with respect to the shuttle vehicle. Its mass properties also will cease to be included into shuttle vehicle mass properties. It will be assumed that a payload, once attached, remains fixed with respect to the shuttle. Preliminary data implies that, in the real-world, this will be the case to within 0.5° . At this point, it would appear that any effects on vehicle inertia tensor resulting from such motion will be sufficiently small as to not require simulation for training purposes. Center of mass shifts permitted are not known, but are also assumed to be insignificant. Precise simulation of continuum effects of such mass property shifts would probably be ruled out in any case due to cost vs. benefit. Rough approximation of retained payload dynamics and resulting momentum effects would be somewhat less costly, but still does not appear to be justified by currently available data. The payload attachment

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simulation will be calculated for each applicable payload once each 100 milliseconds. This rate matches that of the manipulator dynamics and the applicable shuttle mass properties, and is sufficiently fine to avoid noticeable delays in mass property changes and payload release.

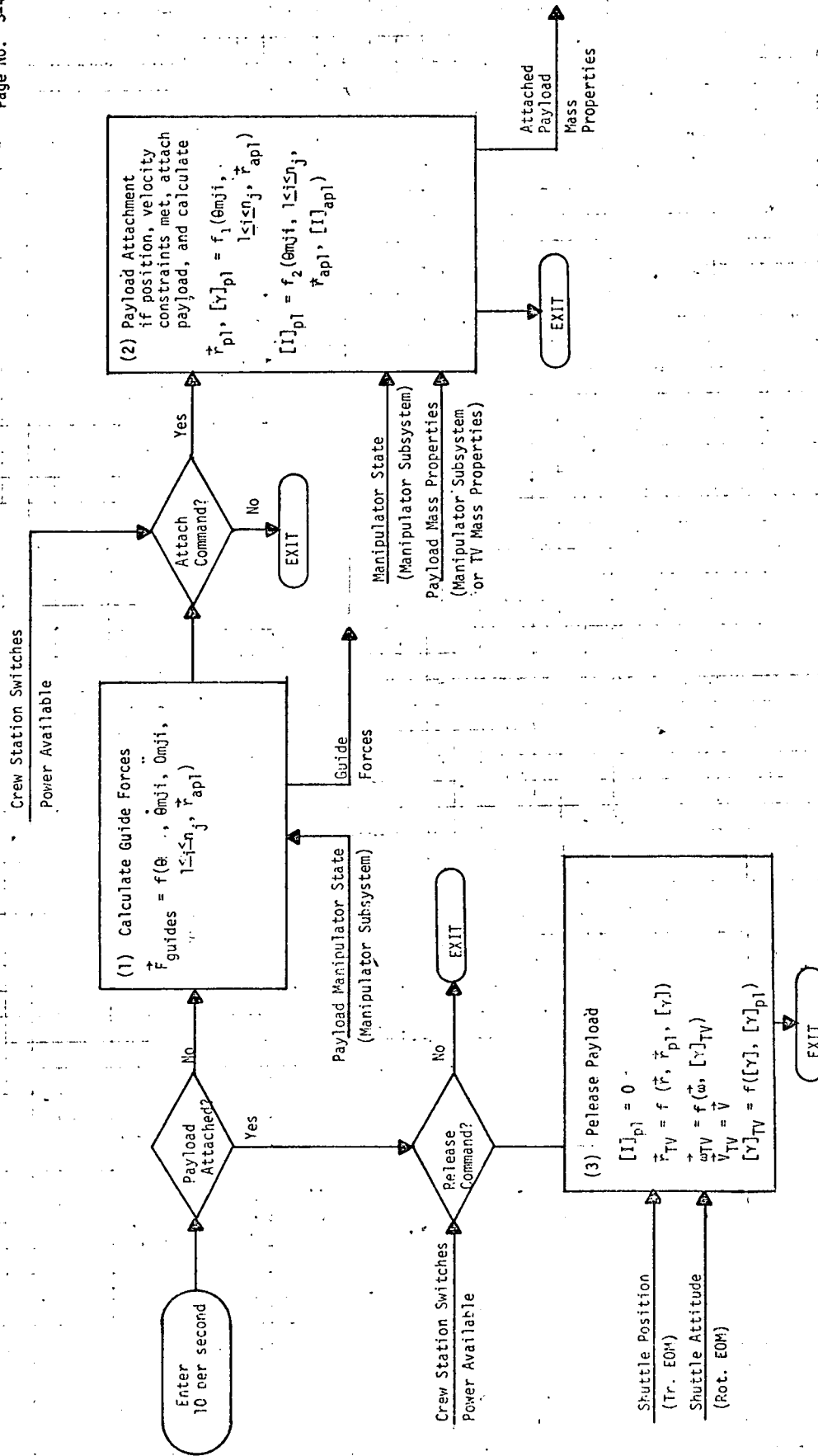


FIGURE 3.3.10.1-1

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Symbol Dictionary for Figure 3.3.10.1-1

\vec{F}_{guides}	Forces exerted by attachment guides upon payload	\vec{r}_{tv}	Target vehicle position
$[F]_{\text{apl}}$	Inertia tensor of manipulated payload	\vec{V}_{tv}	Target vehicle velocity
$[I]_{\text{pi}}$	Inertia tensor of retained payload	$[\gamma]$	Shuttle direction cosines
n_j	Number of arm degrees of freedom	$[\gamma]_{\text{pl}}$	Payload attached attitude
\vec{r}	Shuttle position	$[\gamma]_{\text{tv}}$	Target vehicle direction cosines
\vec{r}_{apl}	Position of manipulated payload	θ_{mji}	Position of e^{th} manipulator joint angle
\vec{r}_{pl}	Retained payload center of mass position	$\dot{\theta}_{\text{mji}}$	Rate of e^{th} manipulator joint angle
		$\ddot{\theta}_{\text{mji}}$	Acceleration of e^{th} manipulator joint angle
		$\vec{\omega}$	Shuttle angular velocity
		$\vec{\omega}_{\text{tv}}$	Target vehicle angular velocity

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3.3.10.2 Payload Manipulator Subsystem

The simulated payload manipulator subsystem simulates the dynamics and interfaces of the shuttle payload manipulators. Inputs to the simulated subsystem include manipulator arm joint and terminal device position commands (from the on-board computers), power available booleans (from the electrical power subsystem) shuttle vehicle translational state and body forces (from translational EOM), shuttle vehicle attitude, angular velocity and total moments (from rotational EOM), payload position (from target vehicle translational EOM or the payload accommodation system), payload attitude (from target vehicle rotational EOM or the payload accommodation), payload mass inertia tensor and c.m. location (from payload mass properties), and crew station switch and circuit breaker settings. Provided these inputs, the manipulator simulation will calculate each manipulator joint angle position and rate, terminal device and deployment device positions, joint potentiometer and tachometer outputs, forces and torques exerted upon the vehicle by the manipulator system, payload translational and rotational state upon release, electrical power loads, checkout system outputs, and relative state of a jettisoned arm. Definition of the vehicle payload manipulator subsystem is quite amorphous and indefinite at this time. The real-world configuration herein simulated is based on what is apparently the best available data, but should not be regarded as a high-confidence delineation of the ultimate real-world system. It is entirely possible that, as real-world system design progresses, substantial changes will be required in this conceptual design. The vehicle possesses two manipulator arms, each of which will be simulated as discussed below. If all proper crew station switches and breakers are set and power is available and the arm jettison switch is thrown, the arm will be jettisoned. The relative state of the jettisoned arm will be maintained until it has safely cleared the vehicle, for simulation of visual cues to verify separation, enhanced visual realism, and collision avoidance training. The jettisoned arm will be assumed to be given a fixed impulse, from which its relative velocity will be calculated once,

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and held constant thereafter. There does not seem to be a great amount of training value in maintaining relative rotational state of the jettisoned arm or inertial state of the jettisoned arm (though they would improve realism). The jettison forces and torques on the shuttle will be simulated. The attachment of the manipulators to the payload doors will be simulated. When the arm is latched, the proper switch and breaker configuration exists, power is available, and the unlatch switch is thrown, the simulated arm will be released, and the arm dynamics simulation initialized with the "stowed" joint angles, and zero angular rates. When the arm is unlatched, the proper switch and breaker configuration exists, power is available, and the unlatch switch is thrown, the orientation of the arm will be checked. If the arm snap ties are properly positioned, the simulated arm will be latched. If, however, the function of the real-world latch switch is to command an arm trajectory to the latching position, after which time an automatic latch command is given, the latches will be actuated by that automatic command. During periods during which the arm is latched, arm dynamics will not be calculated. If latching or unlatching can take place at variable door positions, the initial joint angles upon unlatching will be set, and the proper snap tie positions upon latching will be determined, as appropriate, as functions of payload door position. The arm deployment mechanism will be simulated as active whenever the proper switch and breaker configuration exists, power is available, a switch commanding change in deployment state is thrown, and redeployment is not complete. While active, the mechanism will be considered to move at a constant rate until the appropriate limiting position is attained. Deployment device position, position of the manipulator arm shoulder with respect to the body axis system and power load will be calculated. The terminal device simulated will be a simple grasping device. The terminal device simulation will, however, be kept functionally and physically separate from the remainder of the arm simulation as much as possible. Thus, update by modification to an alternate terminal device

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will be simplified, if it is required. It is assumed that the device will grasp the payload rigidly, and will have only one degree of freedom, namely the joint between the grasping bars. The simulated terminal device will be active when power is available and the proper crew station switch and breaker configuration exists. It is assumed that the terminal device can receive drive signals from either the on-board computers or the manual checkout system. On-board computer signals will be assumed to be the joint position command, while checkout system signals will be assumed to be direct motor torque command, which is at any given time either zero or \pm a fixed number. The terminal device simulation will include servo-loop dynamics if significant in computing motor torques. Terminal device mass properties (which are constant) will be used in conjunction with torque to obtain angular acceleration, angular rate, and angular position of the terminal device joint. Outputs to the checkout system readouts and power load will also be calculated. If the terminal device was just closed (i.e., joint angle reduced below a certain point), the terminal device position is compared to the positions of grasping points of all payloads in the area (obtained from the payload accommodation system or target vehicle EOM as appropriate). If these comparisons indicate that a payload was grasped, its mass and inertia properties will be stored in the appropriate cells and its orientation with respect to the arm's wrist joint will be calculated for use in the arm dynamics simulation. If the terminal device was just opened (i.e., joint angle increased above a certain point), and a payload had been grasped, and that payload is not now attached to the shuttle vehicle by the payload attachment subsystem, the target vehicle Equations of Motion for that payload are initialized.* Payload position, velocity, attitude, and angular rates at release are calculated using current shuttle vehicle translational and rotational state, as well as arm joint angles and angular rates. At release, the mass and inertia of the grasped payload will be reset to the unloaded condition in the arm dynamics simulation. Providing that power is available and crew station switch

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settings are properly configured, the manipulator arm torque motors will be considered active. During times at which the arm is not stowed, when a given joint does not have power available, it is assumed that brakes will be applied to that joint. It is assumed that each joint can receive drive signals from either the on-board computers (in the form of joint position commands) or the manual checkout system (in the form of direct motor torque commands, which are, at any given time, either zero or \pm a fixed number). Servo-loop dynamics will be included in the calculation of torque resulting from drive signals if significant. Torques will be limited to the same values that real-world arm torques are limited. Joint torques will reflect the effects of the malfunction of one of the motors on that joint when appropriate. Checkout system outputs, power load, and torques on each joint are calculated from the input information. Arm dynamics will be simulated by solving the rigid-body equations of motion for the shuttle/manipulator/payload system. Bending frequencies are currently constrained to an amplitude substantially less than the control system tolerance, which is presumably smaller than the minimum accuracy envelope required to perform all required tasks. Thus, the simulation of arm bending effects does not at this time appear to provide sufficient training value to offset the very considerable impact resulting from its inclusion. The data on which this conclusion rests may be invalidated as the arm design develops. When unloaded, the manipulator will be assumed to consist of three segments (shoulder to elbow, elbow to wrist, wrist through terminal device), each with significant mass. When loaded, the mass, inertia properties and center of mass location of the grasped payload will be included in the simulated arm dynamics. Payload center of mass location will be available in terms of a vector from the terminal device to the mass center. Thus, the shuttle/manipulator/payload with the aforementioned approximations is a constrained system of four (or five) rigid masses with at least twelve degrees of freedom. It is not clear at this time to what further extent the

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dynamics problem can be simplified. Certain simplifications can apparently be ruled out, however. Since the system can deploy payloads approximately 1/3 as massive as the shuttle, and since the arm may be useful to provide forces during the final phase of shuttle-to-shuttle docking, the mass of the shuttle cannot be approximated as infinitely large with respect to the grasped payload. Hence, the interaction of the manipulator dynamics with shuttle dynamics must be simulated. Since the arm, during deployment, retrieval, and docking, will brake relative velocities between the shuttle vehicle and massive objects, arm position will not necessarily follow input commands except over very long periods of time. Thus, no such simplifying assumptions may be made. Application of torque to a given joint will either cause motion at other joints, or require opposing torques at other joints. Hence, the dynamics of a given joint cannot be simulated in isolation from other joints (except possibly as a temporary approximation). Joints are provided for motion about all three axes, so planar simplifications are not possible. The effects of joint brakes and position limits on each joint will be included in the arm dynamics simulation. The arm dynamics will reflect the effects of forces and torques (external to the payload system) on the shuttle vehicle and shuttle vehicle angular velocity. The arm dynamics simulation will obtain from these inputs, as well as joint torques and previous manipulator state, the angular accelerations on each joint. These accelerations will be integrated to obtain joint velocities and positions, force and torque exerted by the manipulator upon the shuttle vehicle, orientation of the wrist beam upon which the TV camera and floodlight is mounted, and orientation of the grasped payload, if any. Collision constraints will be simulated. The positions of the elbow joint, wrist joint, and payload (or terminal device if unloaded) will be calculated from the joint angles. The payload will be approximated as a cylindrical solid. All three beams and the payload (or terminal device) will then be checked to insure they are not in collision with any part of

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the shuttle vehicle, a payload, or another arm. If a collision has occurred, the necessary joint angles will be reset and joint rates zeroed to prevent the manipulator/payload from penetrating the vehicle. Accurate simulation of collision dynamics is not assumed to be necessary for training simulation. Since the operator should be trained to avoid smashing the manipulator/payload into the vehicle, it would appear that only the detection of collision must be simulated accurately. Outputs of the joint potentiometers and tachometers are calculated from the true joint positions and velocities. These outputs will also reflect instrument biases and malfunctions, as well as quantization. An iteration rate of 10 per second is applied to the manipulator simulation. This rate should be within the limits of perception, and, with a high fidelity dynamics simulation, should provide adequate response characteristics accuracy. As the real-world on-board computer data interface rate is not currently known, it has not been taken into account. If computer interface rates are considerably higher than this, which is possible, it should be possible to obtain adequate approximations to the outputs to the computer during the interval between arm dynamics recalculation times. Since system performance characteristics appear to be quite sluggish, such approximations are not expected to cause severe degradation of system response characteristics. The conceptual design for the manipulator simulation is sketched in figure 3.3.10.2-1.

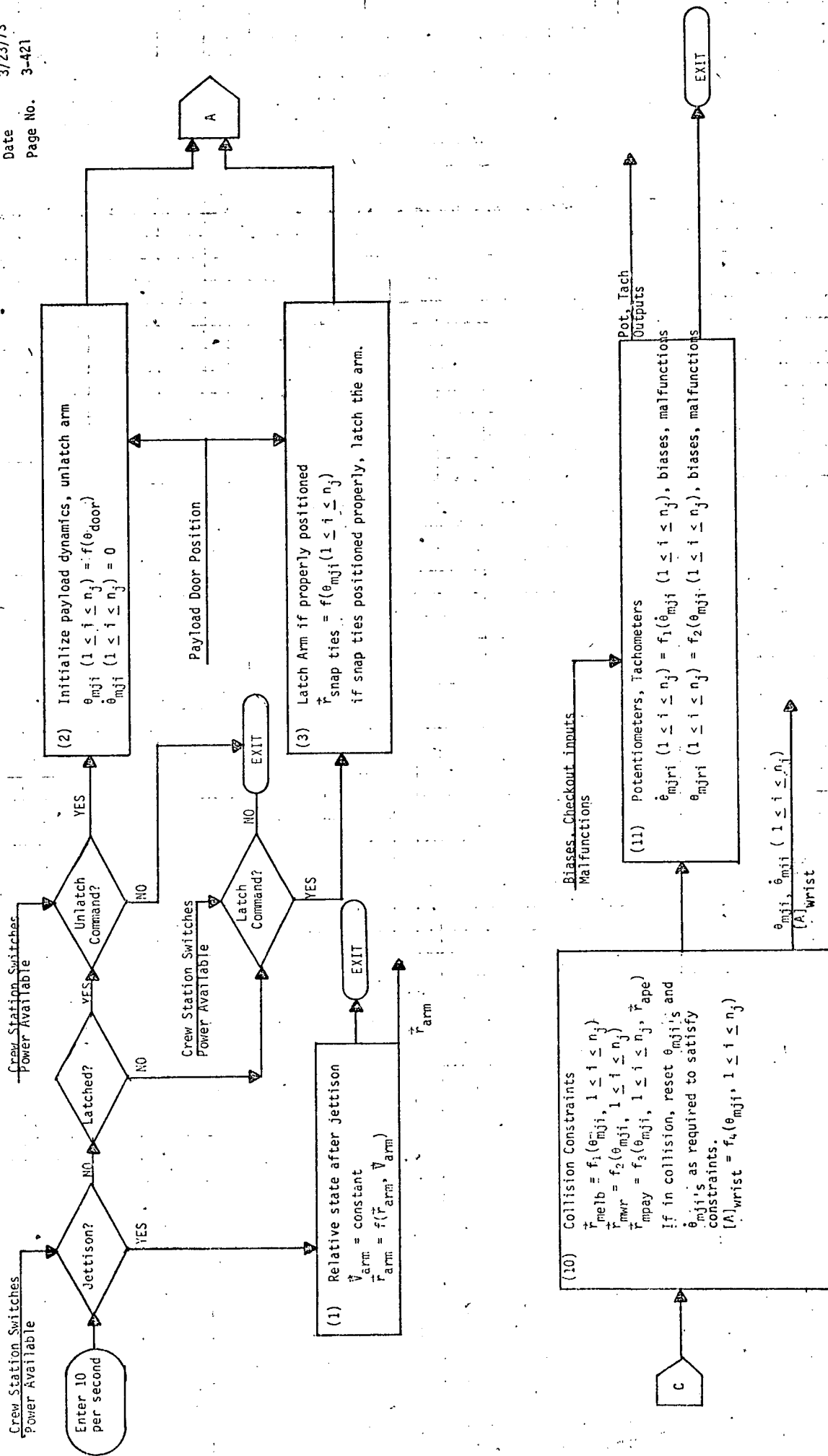


FIGURE 3.3.10.2-1

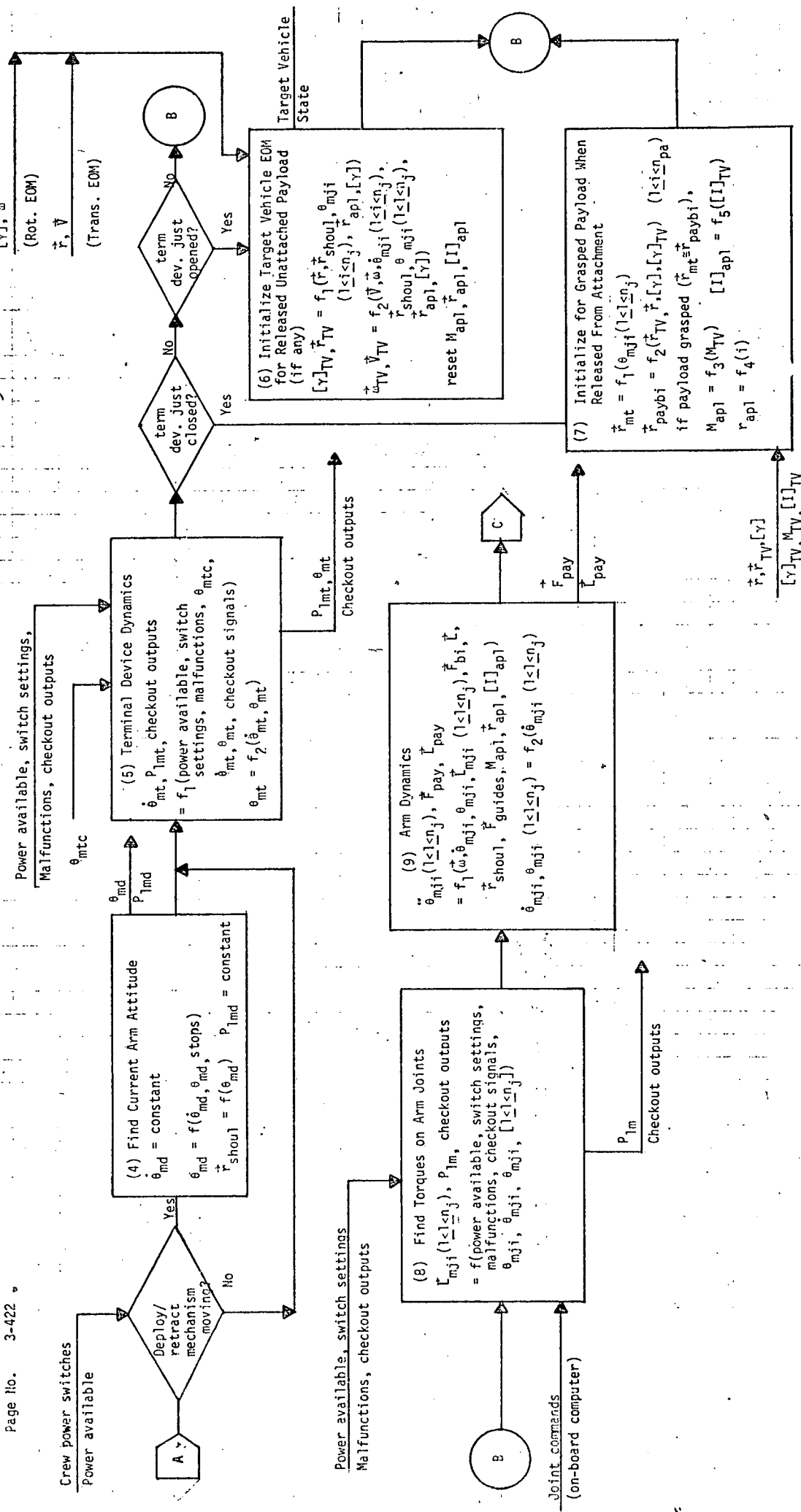


FIGURE 3.3.10.2-1 Page 2

Symbol Dictionary for Figure 3.3.10.2-1

$[A]_{\text{wrist}}$	Wrist orientation matrix	P_{limt}	Power load due to
\vec{F}_{bi}	Body forces on shuttle		terminal device operation
	vehicle (inertial coordinates)	\vec{r}	Shuttle position
\vec{F}_{guides}	Force due to payload	\vec{r}_{arm}	Position of jettisoned arm
	attachment guides	\vec{r}_{apl}	Terminal device to
\vec{F}_{pay}	Force exerted on shuttle		payload mass center vector
	vehicle by manipulator arm	\vec{r}_{melb}	Position of arm elbow
$[I]_{\text{apl}}$	Inertia tensor of attached	\vec{r}_{mpay}	Position of arm payload
	payload	\vec{r}_{mwr}	Position of arm wrist
$[I]_{\text{tv}}$	Target vehicle inertia	\vec{r}_{paypi}	Position of i^{th} payload
	tensor		grasping point
\vec{L}	Total moment on shuttle vehicle	\vec{r}_{shoul}	Position of arm shoulder
\vec{L}_{mji}	Torque on i^{th} arm joint	$\vec{r}_{\text{snapties}}$	Positions of arm latching
\vec{L}_{pay}	Total moment exerted on		snap ties
	shuttle vehicle by manipulator arm	\vec{r}_{tv}	Target vehicle position
M_{apl}	Mass of attached payload	\vec{V}	Shuttle velocity
M_{tv}	Mass of target vehicle	\vec{V}_{arm}	Velocity of jettisoned arm
n_j	Number of manipulator arm	\vec{V}_{tv}	Target vehicle velocity
	degrees of freedom	$[\gamma]$	Shuttle direction cosines
n_{pa}	Number of payload grasping	$[\gamma]_{\text{tv}}$	Target vehicle direction
	points		cosines
P_{lm}	Power load due to arm operation	θ_{door}	Payload door angular
P_{lmd}	Power load due to deployment		position
	device operation	θ_{md}	Deployment device angle

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$\dot{\theta}_{md}$ Deployment device angular rate
 θ_{mji} Position of i^{th} manipulator arm
angle
 $\dot{\theta}_{mji}$ Angular rate of i^{th} manipulator
arm angle
 $\ddot{\theta}_{mji}$ Angular acceleration of i^{th}
manipulator arm angle
 θ_{mjci} Commanded position of i^{th}
manipulator arm angle
 θ_{mjri} Readout of i^{th} joint potentiometer
 $\dot{\theta}_{mjri}$ Readout of i^{th} joint tachometer
 θ_{mt} Position of terminal device
angle
 $\dot{\theta}_{mt}$ Angular rate of terminal
device angle
 θ_{mtc} Commanded position of terminal
device angle
 $\vec{\omega}$ Shuttle vehicle angular
rate
 $\vec{\omega}_{tv}$ Target vehicle angular
rate

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3.3.10.3 Payload Bay Doors Subsystem

The payload door simulation calculates the position of each segment of the payload doors and space radiators, torques exerted on the shuttle vehicle by their motion, their effects upon vehicle mass properties and hydraulic flow. When unlatched and in motion, proximity of the doors to the appropriate latch proximity sensors will be checked on each pass through the program. When proper proximity is achieved (and switches, breakers, power, etc., are properly configured), the latches will be actuated. Latch zip-fastener action will be simulated as a function of time since the proximity sensors were actuated. Door motion will be simulated both with and without space radiators attached. Door motion will take place only when necessary electrical and hydraulic power are available and it is commanded. The angle between the door position when closed and the current door position (measured in the plane normal to the door longitudinal centerline) as well as the angle between the space radiator position when closed and the current space radiator position will be maintained. When in motion, the door will move at an angular rate which is a function only of hydraulic flow available. (No data on door motion is available, but this seems to be a reasonable assumption). The current door and radiator angles will be used to calculate door and radiator center of mass positions and inertia sensors in the shuttle B coordinate frame, for use in shuttle mass properties. When in accelerated motion, the doors will exert a reaction torque on the shuttle vehicle. The real-world door/vehicle dynamics problem is fairly complex, due to the continual vehicle inertia change during door motion. The torques involved in closing both door/radiator combinations (worst case) are internal to the shuttle body, and do not affect the total angular momentum of the system. Thus, system angular momentum should remain constant during the operation. Hence, as the doors/radiators open, since the inertia tensor decreases, shuttle body rates increase to conserve angular momentum. However, other torques (e.g., RCS firings) could alter

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angular momentum during this interval. The total resulting dynamics could be simulated with high precision, but the simulation would not be simple. The dynamics could probably be approximated somewhat more simply, but less accurately. Or, the effect could be ignored. Considering that, during door closing, body rates should ordinarily be low, and that door/radiator mass is probably a fairly small fraction of vehicle mass, and therefore will not unduly affect inertia tensor, and that these dynamics should not involve any important crew cues, it is currently intended to ignore them. If any of the above assumptions are violated as design and procedures development advances, the above conclusion should be altered. The payload door simulation will be iterated 10 times per second, the same rate as most of the remainder of the payload accommodation system. This rate should be sufficient to provide training cues to within the perception of the crew. The conceptual design of the simulation for a given segment is sketched in figure 3.3.10.3-1.

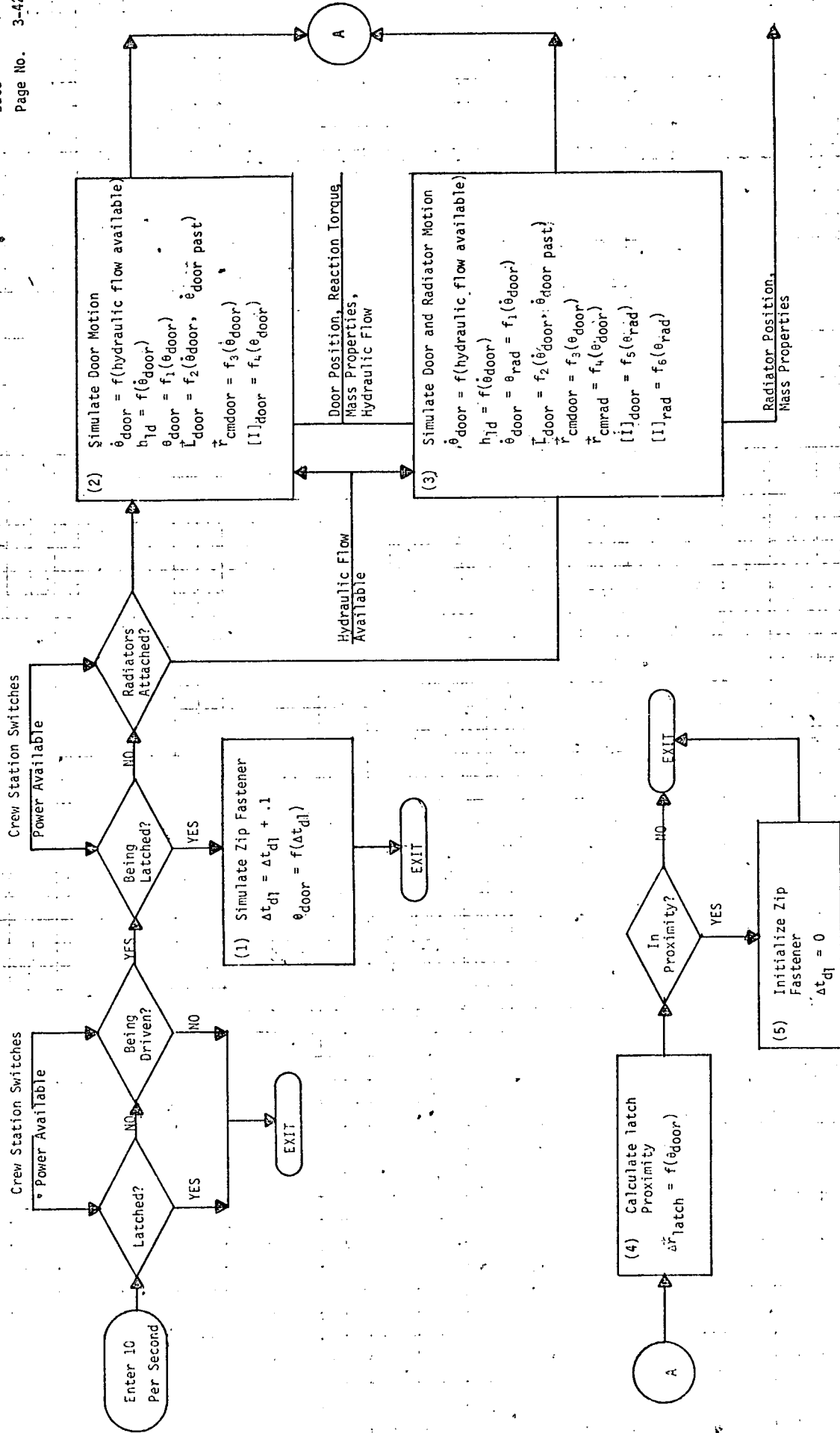


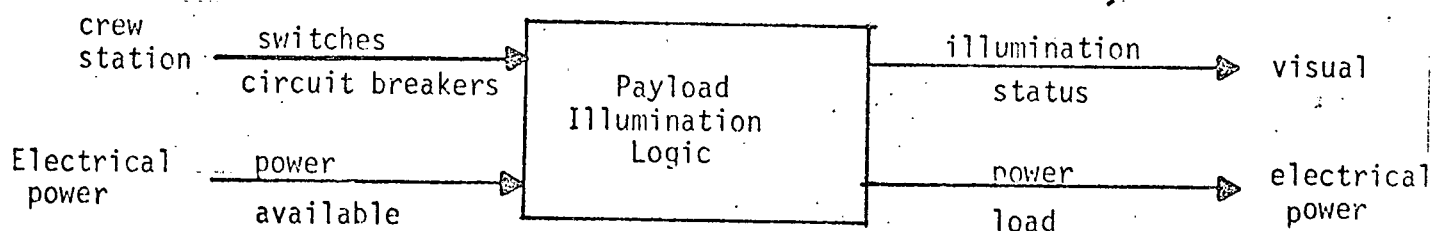
FIGURE 3.3.10.3-1

Symbol Dictionary for Figure 3.3.10.3-1

$[I]_{\text{door}}$	Current inertia tensor of payload door (shuttle B coordinates)	$\Delta \vec{r}_{\text{latch}}$	Vector from door latch point to proximity sensor
$[I]_{\text{rad}}$	Current inertia tensor of space radiator (shuttle B coordinates)	Δt_{de}	Time since latching initiated
\vec{L}_{door}	Reaction torque on shuttle due to accelerated door motion	θ_{door}	Angular position of door with respect to shuttle
\vec{r}_{cmdoor}	Current mass center of payload door (shuttle B coordinates)	$\dot{\theta}_{\text{door}}$	Angular rate of door with respect to shuttle
\vec{r}_{cmrad}	Current mass center of space radiator (shuttle B coordinates)	θ_{rad}	Angular position of radiator with respect to shuttle

3.3.10.4 Payload Illumination Subsystem

The simulated payload bay illumination subsystem will determine whether each of the payload bay lights are lit, and calculate the resulting power loads. The appropriate crew station switches and breakers, as well as the appropriate power available boolean, will be checked to determine whether each light is on. Each illuminated light will provide a characteristic constant increment to the total power load from the payload illumination subsystem. The illumination status of each light will be provided to the simulated visual system.



3.3.10.5 Payload TV Subsystem

The simulated payload bay television subsystem will determine whether each of the payload bay television cameras are in operation, calculate the orientation of all moveable cameras, determine whether each of the payload handling station television monitors is in operation, and calculate the resulting power loads. A camera will be simulated as on when the appropriate crew station switches, crew station circuit breakers, and power available booleans exhibit the correct configuration. Each operating camera or monitor will provide an increment to the total power load from the payload bay television subsystem. The operational status of each camera and monitor will be provided to the simulated visual subsystem. The orientation of the manipulator arm wrist TV cameras will be calculated from data received

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from the simulated payload manipulators. Orientation of other moveable attitude cameras will be calculated from crew station switch inputs (taking due account of power available), and manipulator orientation if an automatic track capability exists. The same television logic will be used to simulate other on-board television systems.

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Symbol Dictionary

$[A]_{\text{wrist}}$ Manipulator wrist axes
to body axes direction

cosines

i_{camonj} j^{th} tv camera on/off

i_{mononj} j^{th} tv monitor on/off

\vec{t}_{cam} Direction of center of
camera field of view

\vec{j}_{cam} Direction of camera

Vertical axis

n_c Number of tv cameras

n_j Number of manipulator joints

n_m Number of tv monitors

P_{lptv} Payload tv system
power load

\vec{r}_{cam} Position of camera

θ_{mji} Position of i^{th}
manipulator joint

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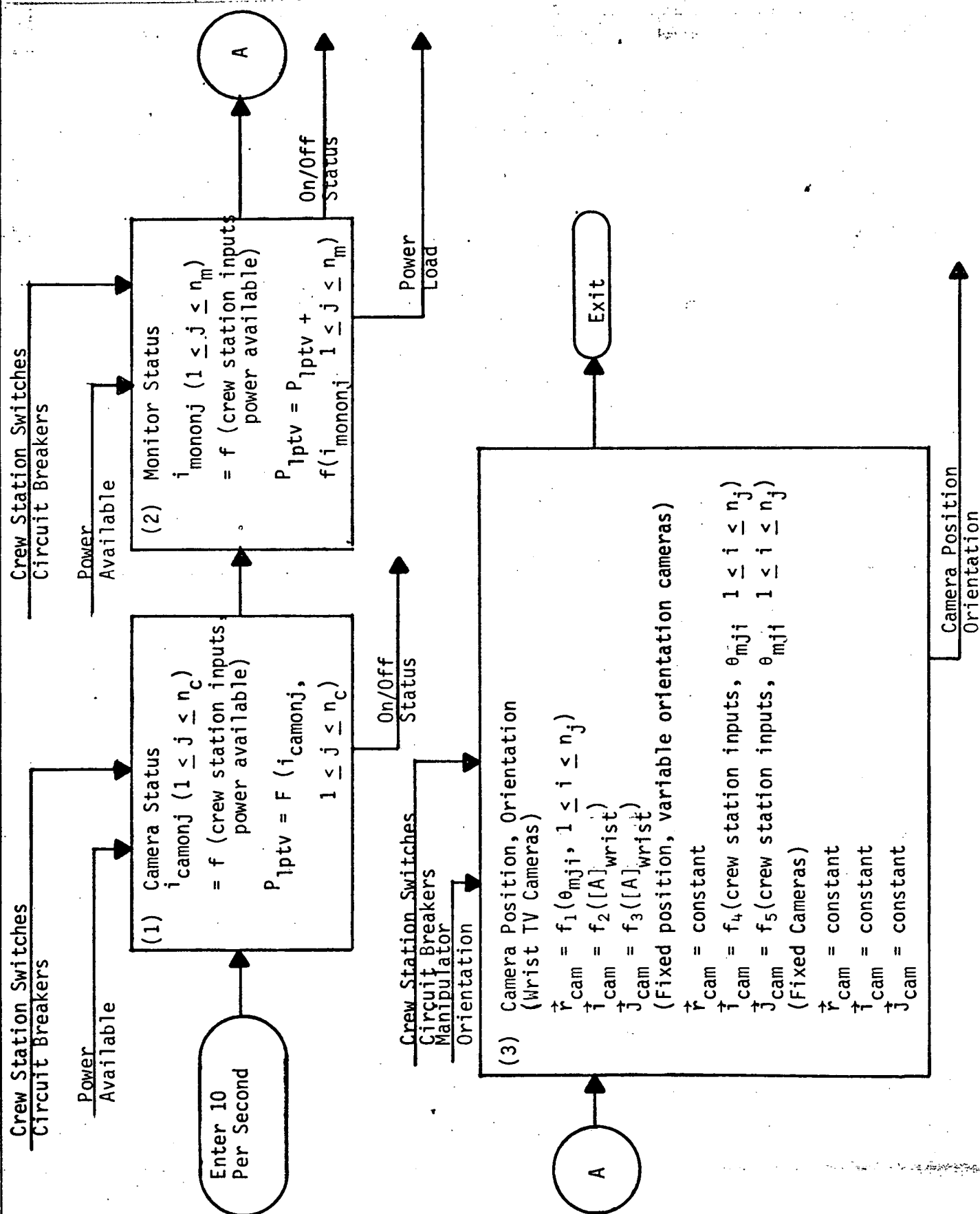
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3.4 System Software Conceptual Design

3.4.1 Simulator Control Software

3.4.1.1 Data Recording

The data recording routines will output internal simulation data values in a format usable by the instructor for trainee evaluation and debriefing. There are three main data recording routines.

3.4.1.1.1 X-T Recorders

This routine reformats and rescales internal data values into analog output signals usable by a standard X-T strip recorder. The parameters processed by this routine will be selectable by a CRT page.

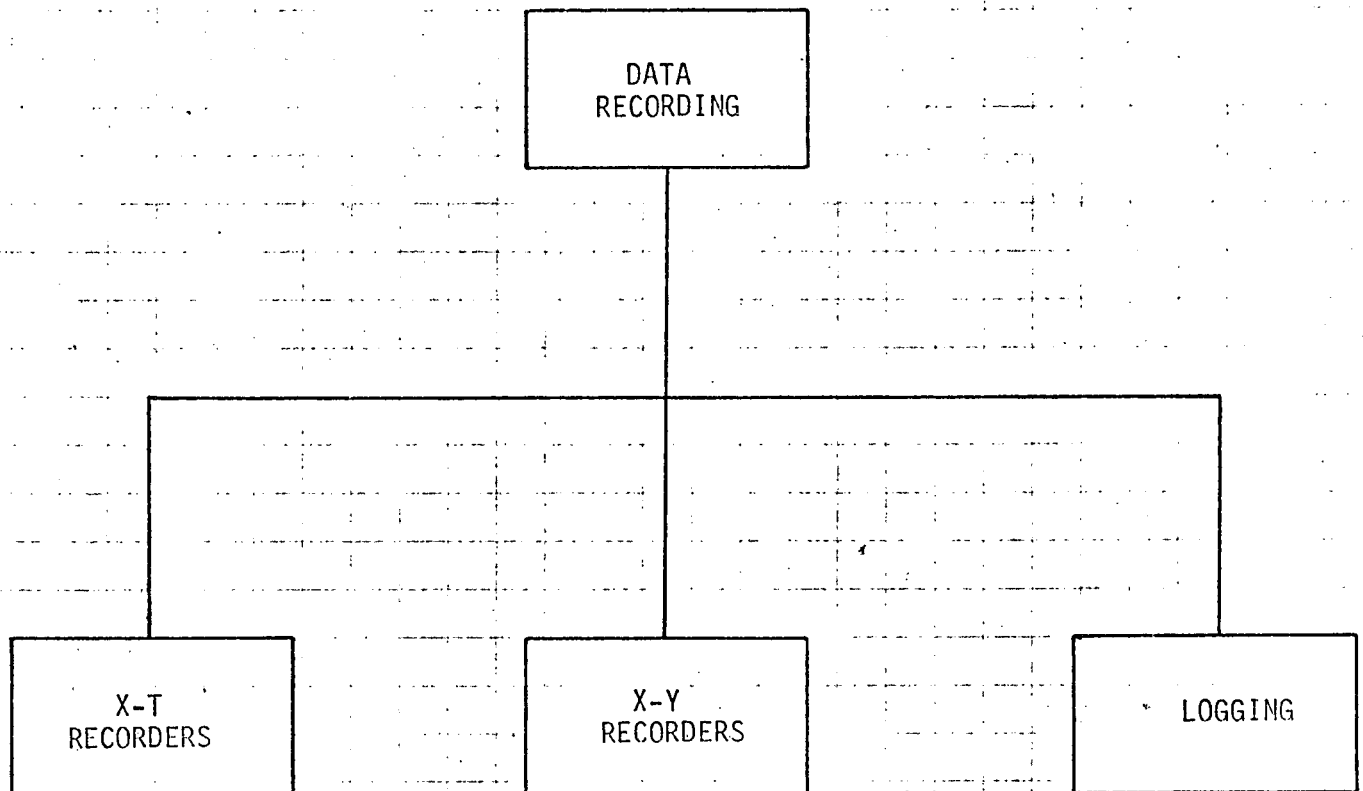
3.4.1.1.2 X-Y Recorders

This routine reformats and rescales two internal parameters and generates analog output signals, allowing a standard X-Y plotter to plot one parameter versus another. The parameters processed by this routine will be selectable by a CRT page.

3.4.1.1.3 Logging

This routine outputs, at a minimum 20/sec. rate, raw parameter values, along with header and formatting information. This output will be placed on magnetic tape in a form usable by an off-line routine which will produce hard copy listings of the parameters. The recording rate of the parameters, as well as the identification of the parameters, will be selectable by a CRT page.

FIGURE 3.4.1.1-1 DATA RECORDING



3.4.1.2 Real-Time Input/Output

The real-time input/output routines are responsible for transferring data between the simulator data pool and the DCE mini-computers. Additionally, the RTIO will maintain the data flow to MCC, and output the telemetry down link data. Thus, the RTIO may be viewed as containing seven separate functions.

3.4.1.2.1 Digital Input

This routine will input discrete data bits from switch-type devices. These inputs will be accepted in an unpacked form from the DCE mini-computer.

3.4.1.2.2 Analog Input

This routine will input data from analog devices. This data will be converted to host computer floating point format by the DCE mini-computer.

3.4.1.2.3 MCC Input

When integrated with MCC, this routine receives the interface data, verifies correctness, and presents the data to the simulation routines.

3.4.1.2.4 Digital Output

This routine will output discrete data bits to lamp and readout-type devices in the form of one bit per computer word. The DCE mini-computer will be responsible for packing the data for the linkage.

3.4.1.2.5 Analog Output

This routine will output data to be displayed on meter-type devices. This data will be output in host computer floating point format to the DCE mini-computer which will convert it to DCE acceptable format.

3.4.1.2.6 MCC Output

When integrated with MCC, this routine will collect data from the simulation routines, format the data, provide check sums, and output the interface data to MCC.

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3.4.1.2.7 Telemetry Output

When integrated with a complex that requires telemetry data from SMS, this routine will collect the data from the simulation routines, format it, and output the data to that complex.

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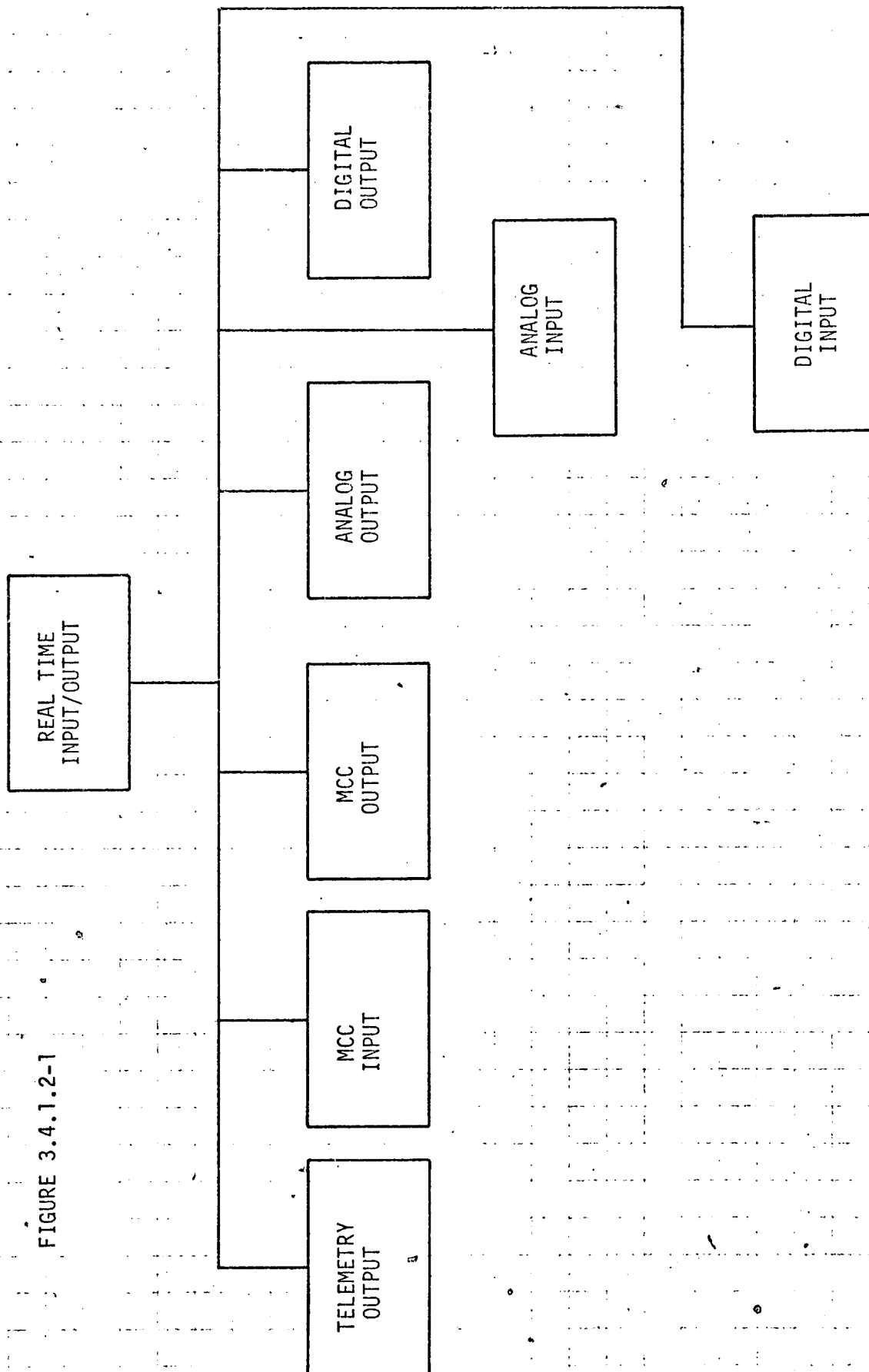
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3.4.1.3 Synchronous Simulation Program Processor (SSPP)

This package serves as the focal point for the execution of the software modules that must execute in a cyclic manner.

The basic jump list management functions incorporated in conventional simulation packages are handled by this module. Thus, program sequencing and iteration rates are a matter of position within the jump list.

In addition to the module address, each element of the jump list will contain flags indicating for which mission phase the module is required. If the module is not required during the current mission phase, it will not be executed.

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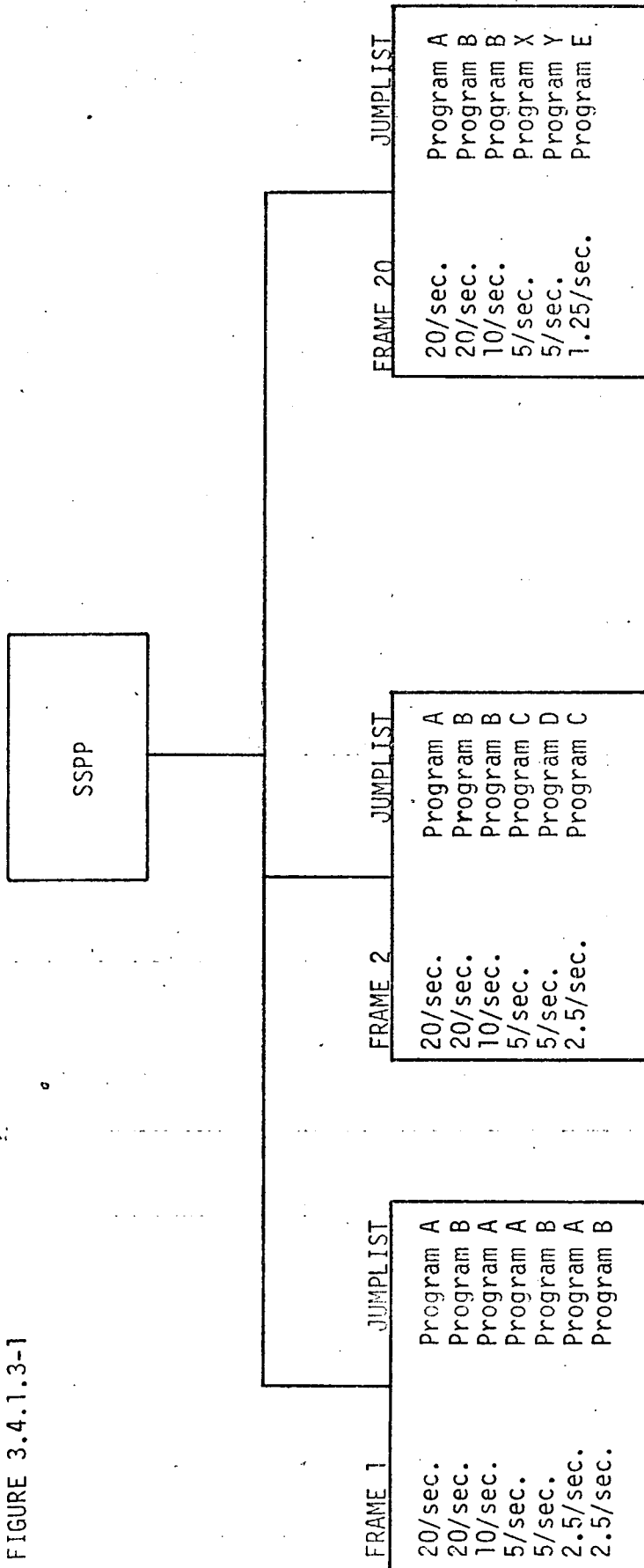
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FIGURE 3.4.1.3-1



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3.4.1.4 Master Timing

The master timing routine is responsible for maintaining the correct time references for the simulator. This includes maintenance of simulated Greenwich Mean Time, simulated Mission Elapsed Time, simulation clocks, event timers, and any special time words (for syncing with MCC, DCS, TM, etc.).

Output data compatible with any computer driven time displays will be generated by master timing.

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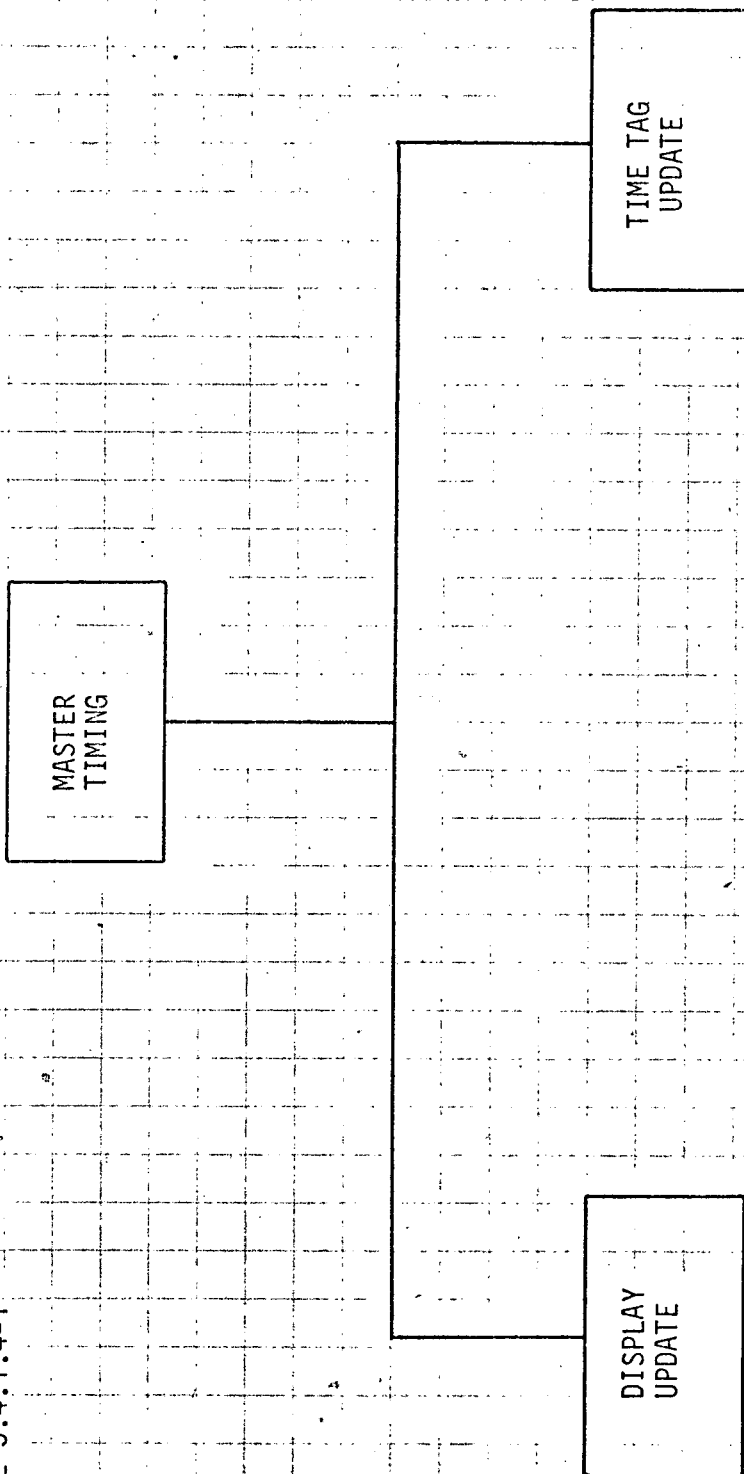


FIGURE 3.4.1.4-1

3.4.1.5 Master Control

The master control program will provide the instructor-operators with the capability of controlling the simulation exercise. This program will respond to switch inputs actuated by the instructor-operators and will provide feedback so that the simulator mode will always be displayed to the instructors.

The following simulator modes will be provided for in the master control program.

3.4.1.5.1 OPERATE

This is the "normal" or operational mode of the simulator. When in "OPERATE," all real-time software is executed and all time constants or integration delta times are set at their real-time values.

3.4.1.5.2 FREEZE

This is the "stop action" mode in which all real-time software is executed, but all integration delta times are set to zero. In this manner, all logic equations and all computations not affected by time are executed, but the simulator's problem is "frozen" in time.

3.4.1.5.3 RESET

This mode provides a means of initializing all reset parameters in the simulator. The initialization data will be read into core memory upon request from the instructor. The instructor will use the CRT keyboard to specify the reset point number.

3.4.1.5.4 WRITE RESET

This mode will cause "a snapshot" of initialization data and this information will be written on mass storage. The reset point identifier and the initialization data will be written on mass storage when the instructor-operator

requests this function via a CRT page. This function will be operational in the "OPERATE" or "FREEZE" mode.

3.4.1.5.5 SAFE STORE

This mode (when enabled) will provide a means of automatically generating a set of initialization points on a time basis. One initialization point will be generated every ten minutes in this mode. A CRT displayable record identifying each point will be saved as each point is transferred from core to mass storage. This record will provide the instructor with a means of identifying a particular "SAFE STORE" point and returning to it via the "RESET" function.

3.4.1.5.6 STEP-AHEAD

This mode will provide a means of accelerating the simulation through periods of trainee inactivity in faster than real-time. The vehicle will remain in an inertial hold mode and simply translate through time at a minimum of ten times real-time. This mode will be activated by entering the delta time necessary to reach desired mission time via the CRT keyboard. When the desired time has been reached, the simulator will automatically switch from the "STEP-AHEAD" mode to the "FREEZE" mode.

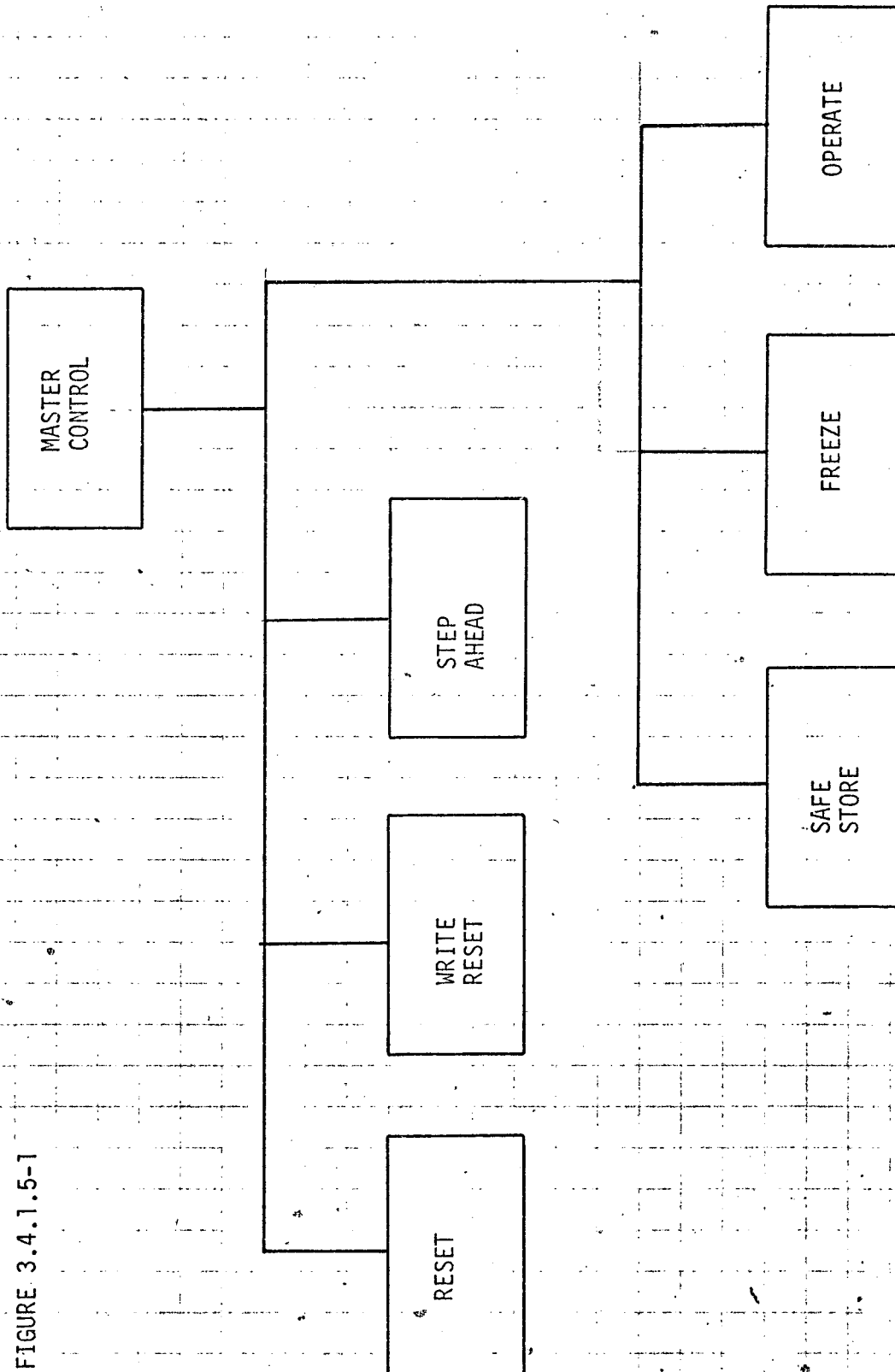


FIGURE 3.4.1.5-1

3.4.1.6 Advanced Training

This system is intended to serve as a helpmate to the instructor during a training session. The advanced training system will aid the instructor in four primary ways.:

1. The system will allow a recording of trainee activities to be made which can be replayed later, thus repeating the actions made by the trainee for post maneuver critique.
2. The system will allow a library of prerecorded maneuvers to be constructed which will allow presentation of "OPTIMUM" solutions to an exercise.
3. The system can relieve the instructor of many routine simulation duties, e.g., insertion of malfunctions, by the use of a predefined mission profile.
4. The system will allow "IN FLIGHT" data to be gathered for later hardcopy. The data gathered will aid in a full and meaningful debriefing of the trainee's activities during the simulation session.

3.4.1.6.1 Record/Playback

This system allows objectives 1 and 2 above to be satisfied. There are five principal elements to this system.

3.4.1.6.2 Training Recording

This routine allows internal simulation data values to be recorded on mass storage. The parameters to be recorded will be those that allow student activities to be faithfully reproduced. This routine will also contain control logic to monitor the recording, supply indications relating to number of recordings made, recording time remaining, etc.

3.4.1.6.3 Training Playback

This routine causes the data recorded by the training recordings routine to be reinserted into the simulation data pool. This routine will contain

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control logic to monitor the playback and, when the playback is complete, insure that all primary controls are in a position to allow a safe flyout from this point should the instructor desire.

3.4.1.6.4 Demo Playback

This routine is analogous to training playback, the principal difference is that the input data comes from the "DEMO LIBRARY" instead of a scratch area of mass storage.

3.4.1.6.5 Pack/Unpack

During recording, this routine gathers the simulation data values to be recorded and packs them into an output buffer. Booleans are packed into whole words for maximum recording density. During playback, the recorded values are unpacked and restored to their proper location in the data pool.

3.4.1.6.6 Input/Output

This routine handles all I/O to the mass storage device(s) used to contain the recorded data. This routine will also form check sums to insure the integrity of data transferred.

3.6.1.6.7 Automated Training

This system satisfies objectives 3 and 4 of the above section by allowing the instructor to predefine a training scenario which is to be followed during the training session.

Once the predefined scenario has been brought into the computer, the instructor need only release the computer to the automated training system and training will proceed as defined. During the time the automated training system is in control, the instructor still has full control over the insertion of additional malfunctions, or to inhibit the insertion of the predefined malfunctions.

At any time during the scenario, the instructor may reassume direct control of the simulator, effectively cancelling the predefined profile.

In addition to automated mission profiles, the system allows for the generation of predefined data gathering modules. These modules allow the instructor to predefine data values which are to be monitored at specific times and hard copied.

As an example, during the landing approach, the instructor may wish to know the value of the following parameters as the spacecraft crosses the outer marker:

Altitude

Airspeed

Heading

Deviation from Localizer Center Line

Deviation from Glide Path Center Line

If the instructor must wait for the outer marker indication, he cannot devote full attention to the trainee. A performance monitor module may be predefined to gather this information for him, freeing the instructor from this task.

To implement the automated training system, the following routines will be required.

3.4.1.6.8 Module Loader

This routine responds to instructor input by bringing into the computer the selected automated training or performance monitor module. Any references to the simulation data pool, as well as any other software linkage requirements, are satisfied by this routine.

3.4.1.6.9 Malfunction Insertion Handler

This routine interfaces the active automated training module with the simulation data pool, allowing preprogrammed malfunctions to enter the

simulation problem. Additionally, this routine will build entries in the table of active malfunctions.

3.4.1.6.10 Output Spooler

This routine will output, to a line printer or mass storage, the formatted data and explanatory text generated by the automated training and performance monitor modules.

3.4.1.6.11 Conversion Routines

These routines reformat the internal binary data into printable characters. The implemented conversions will include Hexadecimal, Octal, Binary, Floating point and integer.

3.4.1.6.12 Module Sequencer

This routine executes and controls the automated training and performance monitor modules resident and active in the computer. Subroutine linkage to all internal and external routines needed by the modules will be satisfied by the sequencer. This routine will also maintain internal clocks and timers which will be available to the modules.

3.4.1.6.13 Automated Training Module

This package contains the predefined logic required to control the simulator as defined in the mission profile.

3.4.1.6.14 Performance Monitor Module

This package contains the predefined logic required to gather the simulation data required for debriefing or post training session evaluation.

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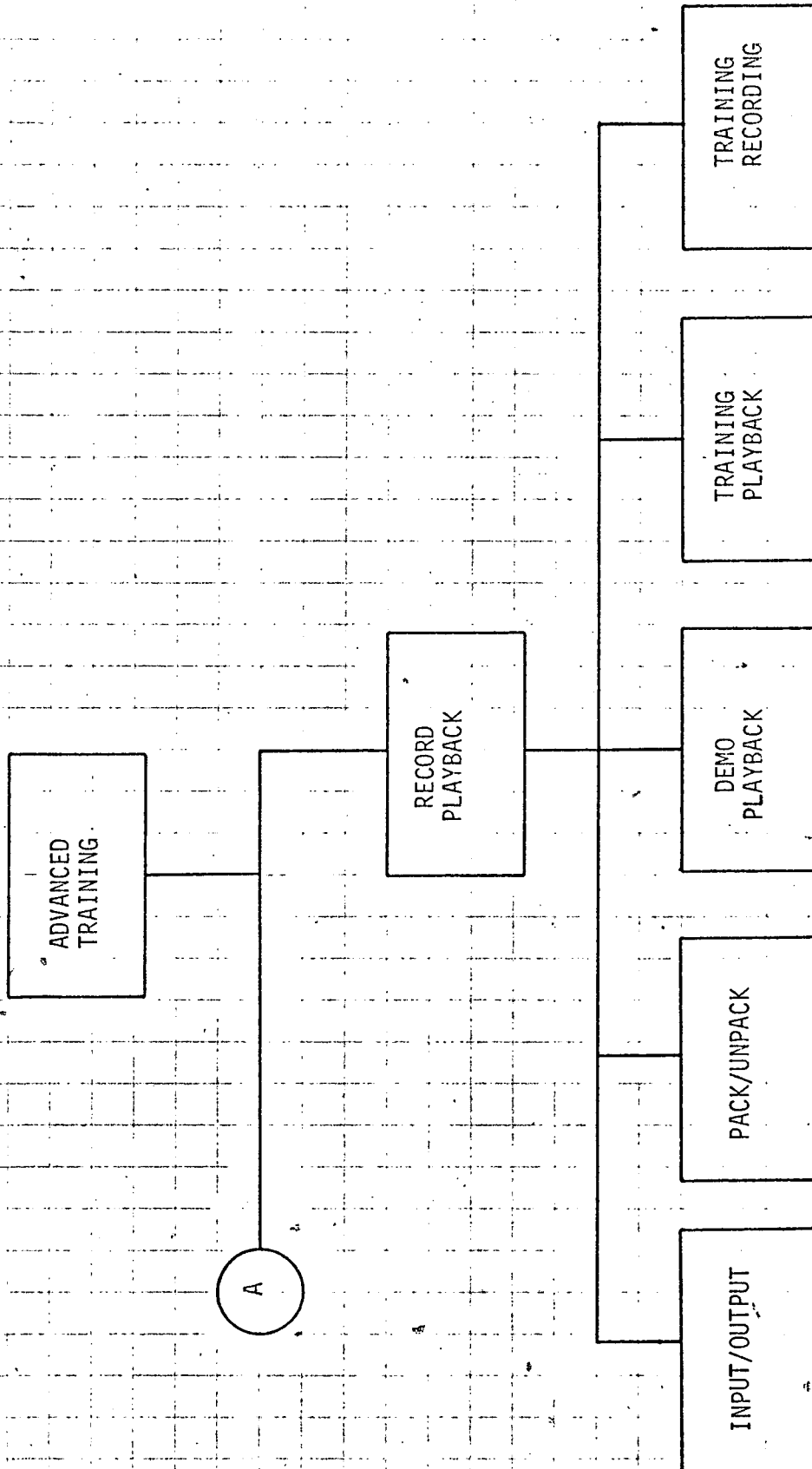
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FIGURE 3.4.1.6-1



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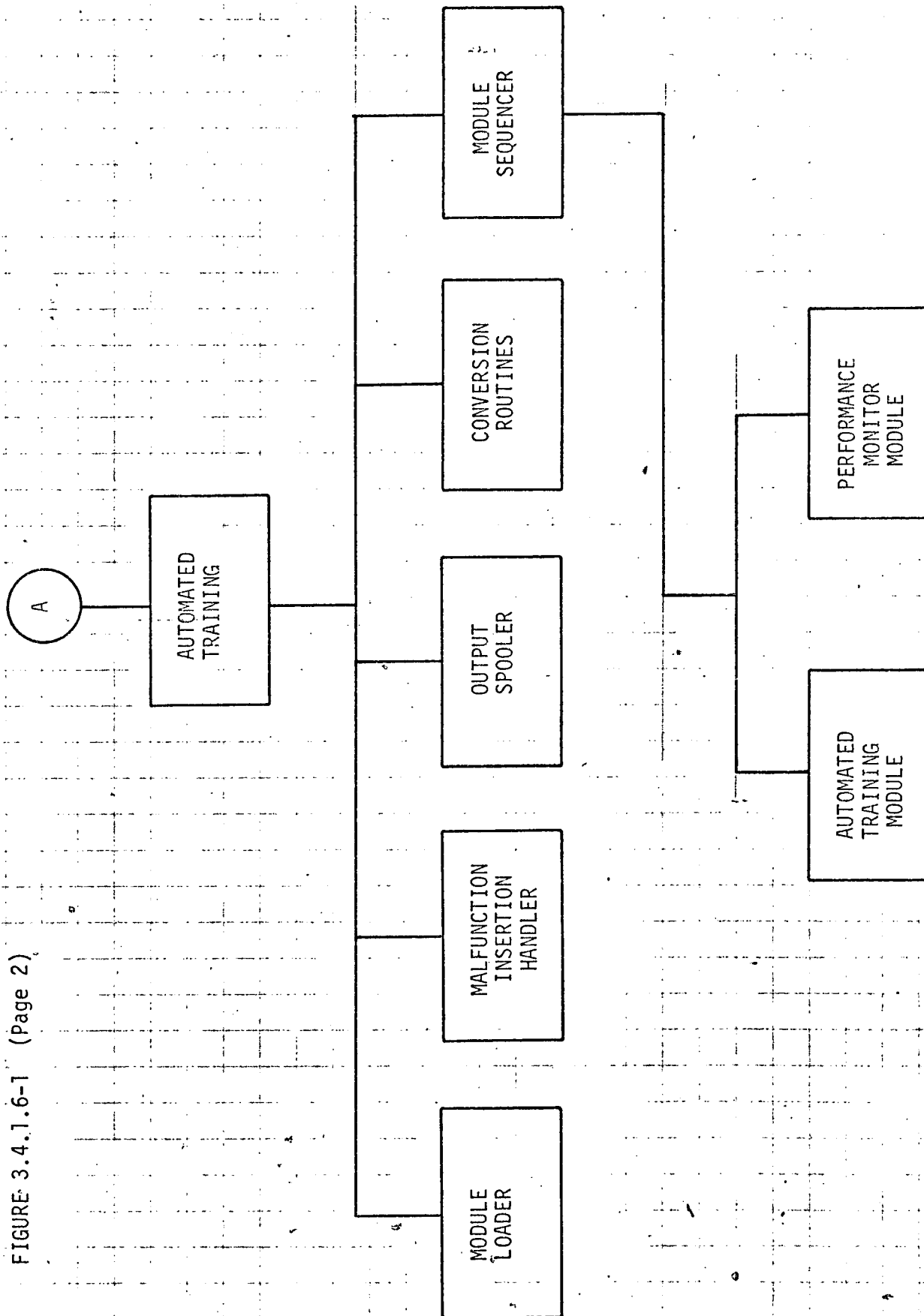
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FIGURE 3.4.1.6-1 (Page 2)



3.4.1.7 CRT Pages

"CRT PAGES" is the generic name for all software processed by the CRT off-line processor that will be executed during the real-time simulation. Although there can be many different types of CRT pages available in real-time, it is felt that these pages will fall into seven general classes:

3.4.1.7.1 Panel Pages

These displays represent physical crew station panels; switches, lights, readouts and meter outputs on the crew station panel are repeated on panel pages.

3.4.1.7.2 Malfunction Pages

These pages are used to introduce malfunctions into the simulation problem. Additionally, the pages build internal tables which allow a malfunction page to "remember" what malfunctions are in the simulation problem.

3.4.1.7.3 Special Purpose Pages

These pages provide "one of a kind" displays. Examples of this type of page would include the event time monitor (which monitors crew station switch and analog inputs and will display to the instructor the occurrence of any crew activity), and the tripped circuit breaker page.

3.4.1.7.4 Utility Pages

These pages serve as a communications media between the instructor and the principal control and display routines in the simulator. Functions such as reset, step-ahead, write-reset are controlled by utility pages. The parameters monitored by the X-T, X-Y, and logging routines may be changed by utility pages.

3.4.1.7.5 Engineering Support Pages

The engineering support pages constitute perhaps the largest group of pages. These pages are useful in performing a detailed analysis of a simulated system. Depending upon how they are programmed, elements from each of the above classes of pages may be included in a support page.

3.4.1.7.6 External Interface Pages

These pages display the interface data streams between the "Spacecraft" and the "Ground". The telemetry downlink and DCS uplink data streams will be displayable by these pages. Any additional data streams that may be unique to an integrated simulation will also be displayable by this type of page.

3.4.1.7.7 Crew Station Setup and Verification (CSSUV) Pages

These pages provide for rapid checkout and verification of crew station controls. Each CSSUV page will inspect a section of the crew station and compare those controls against a pre-defined 'DESIRED' value, indicating to the instructor which controls are not physically in the desired position. When the controls are set in accordance with the desired positions, the CSSUV page will 'MOVE ON' to the next page in sequence.

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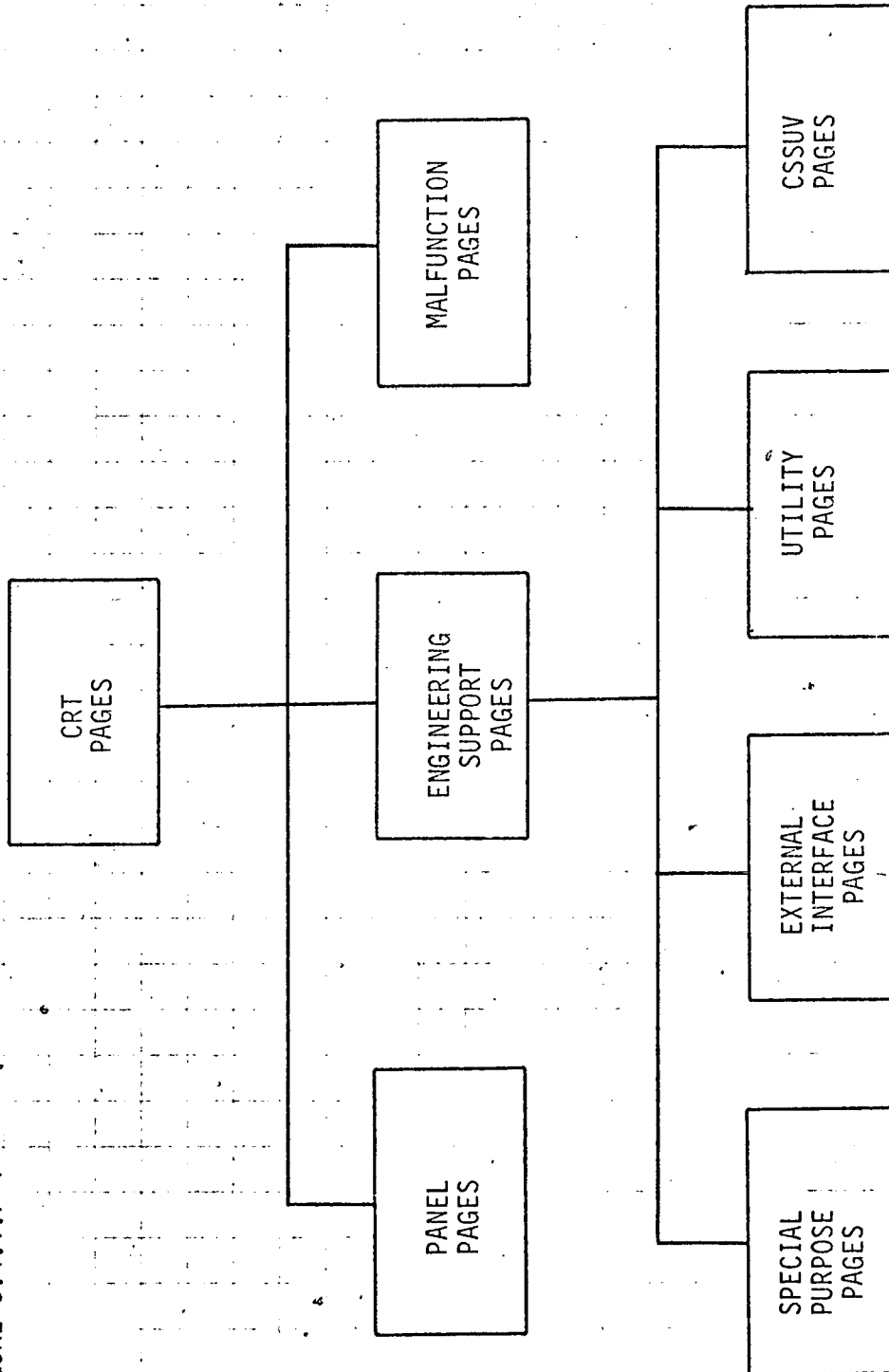
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FIGURE 3.4.1.7-1



3.4.1.8 CRT Interactive Processor

The CRT interactive processor supports two prime functions: execution of CRT page programs and CRT keyboard entry. Each function is delineated below:

3.4.1.8.1 Cyclic Routines

These routines directly support the CRT page programs, thus they execute in a cyclic fashion. The prime routines of interest are:

3.4.1.8.2 Top Line Processor

This routine is responsible for maintenance of the top line display on all CRT's. This maintenance will include updating of mission times, ground station contact, etc.

3.4.1.8.3 Page Executive

The CRT page programs are executed under control of this routine. The page executive also performs the final linkage between the relocatable CRT page and the common data pool.

3.4.1.8.4 Look and Enter

This routine will maintain correct value displays on any screen which has an active look and enter request.

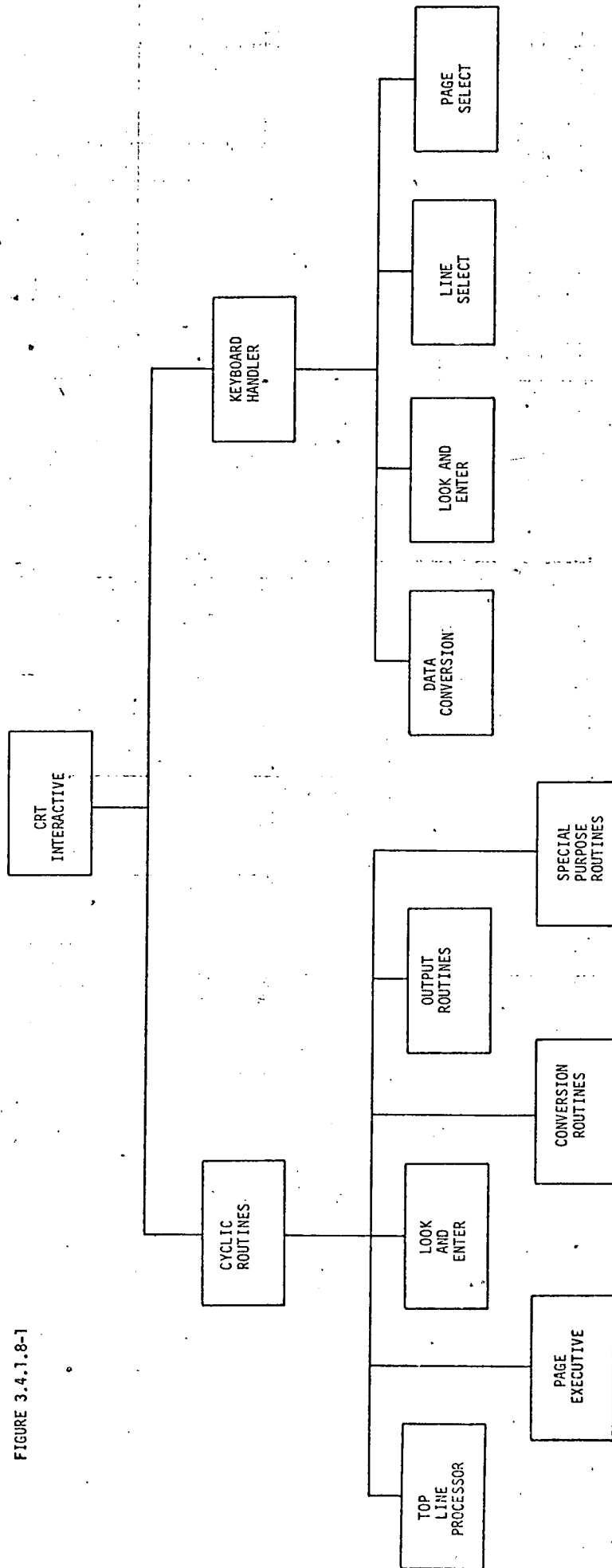
3.4.1.8.5 Conversion Routines

These routines convert the computer binary data to a form displayable on the CRT screen. Possible types of conversion will include hexadecimal, octal, floating point, integer, and binary.

3.4.1.8.6 Output Routines

These routines cause the CRT display to be transferred to the CRT hardware.

FIGURE 3.4.1.8-1



3.4.1.8.7 Special Purpose Routines

These routines interface with the CRT pages described in 3.4.1.7.3, and provide the very specialized functions required to support those pages. The routines involved in this area will include an event time monitor processor, a tripped circuit breaker processor, and a circuit breaker malfunction processor for use by the panel pages.

3.4.1.8.8 Keyboard Support

These routines respond to CRT keyboard input and perform the required actions to complete the request. Examples of these routines will include:

3.4.1.8.8.1 Page Select

This routine will search a catalog of available CRT pages and load the selected page if found.

3.4.1.8.8.2 Line Select

This routine will scan tables built by the CRT off-line processor and will build a scratch pad line entry for all defined input fields.

3.4.1.8.8.3 Look and Enter

This routine allows the instructor to view and/or modify any data pool parameter, by name, independent of any CRT page displayed on the CRT screen.

3.4.1.8.8.4 Data Conversion Routines

These routines accept as input CRT keyboard characters and convert them into computer binary numbers. The conversion types will include hexadecimal, octal, integer, Boolean, and floating point data.

3.4.1.9 Simulation Software Structure

The four representative mainframe configurations are presented in section 3.5.3 of this document. This section will describe four software structures, one per configuration, that may be used to perform the required simulation task.

3.4.1.9.1 General Design Requirements

In order to arrive at any simulation software structure, there are several general requirements that must be made. This section will delineate the major requirements applicable to all the simulation software structures.

3.4.1.9.1.1 Programming Language

The majority of the simulation software will be programmed in FORTRAN, or a higher level language. The software that cannot be programmed in a high level language due to the nature of the functions to be performed will be programmed in the assembly language of the computer.

3.4.1.9.1.2 The Operating System

The Operating System will provide a hospitable environment for the required real-time simulation software and can provide all required services. These services will be delineated elsewhere in this report.

3.4.1.9.1.3 Iteration Rates

Each discrete module of the simulation software will require iteration (recurrent execution) at one of the following rates: 20, 10, 5, 2, or 1 times per second.

3.4.1.9.1.4 Asynchronous Event Synchronization

The processing of an asynchronous event can be performed synchronously, (i.e., input elements can be accumulated at random intervals

(asynchronously) and, at some point, processing for the total input group can be initiated and synchronized with other cyclic activities.

3.4.1.9.1.5 Input/Output

A request for I/O does not cause the requesting activity to relinquish either execution control or computer resources until the I/O is complete.

3.4.1.9.1.6 Programming Considerations

The OS environment and services provided for real-time mode will be such that the simulation programmer can dedicate himself to the actual simulation problem and be relieved of recreating or duplicating OS functions wherever possible.

3.4.1.9.1.7 Structure Concepts

Since the Shuttle Mission Simulator software, like any other real-time flight simulator, is basically a synchronous entity, a structure must be developed that will insure that this functional format is maintained.

Such a structure implies a capability for independently programming separate modules and later collecting them into a single entity for execution. It also suggests a capability for global external naming (labeling) in both the High Level and Assembler elements so that proper inter-module communication can be established.

3.4.1.9.1.8 Data Pool Concepts

The named data values required by the simulation software will fall into two major classes:

- Internal
- External

Internal data values exist within an individual program and are

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used only by that program. External data values are shared between several programs.

All external data should be collected into one area freely accessible by all software modules. Since a high level language will be the basic programming language, a named common feature can be used. These named common areas can be organized by simulated system, data type, data function, or by any other method that is convenient.

Since there exist named data value interdependencies between program modules, nonsequential access to the data pool is required.

3.4.1.9.2 Simulation Software Structure in the Univac Configuration

The Univac 1110 configuration consists of four CAU's sharing 262K primary storage, and 512K extended storage per crew station.

3.4.1.9.2.1 General Requirements

The following requirements apply directly to the structure definition:

3.4.1.9.2.1.1 CAU Execution Rate

Each CAU is capable of executing at least 1.5 million instructions per second. This rate will include all memory conflicts.

3.4.1.9.2.1.2 Program/CAU Dependency

A direct relationship can exist between a particular program and a particular CAU.

3.4.1.9.2.1.3 Operating Systems

The operating system will be EXEC 8, or an upward compatible system.

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3.4.1.9.2.1.4 Execution from Extended Storage

A CAU cannot execute less than 0.6 MIP when the instruction stream comes completely from extended storage.

3.4.1.9.2.1.5 Parallelism

Large portions of the simulation software can be executed in parallel.

3.4.1.9.2.1.6 Serial Execution

When the simulation software must be executed in a serial mode, that software will be executed in one, and only one, CAU. The computational demand does not exceed the limit of 3.4.1.9.2.1.1 or 3.4.1.9.2.1.4 above.

3.4.1.9.2.1.7 External Interrupts

Upon the occurrence of an external interrupt, the operating system will pass control to one unique entry point in the simulation software package.

3.4.1.9.2.1.8 Operating System Size

The operating system will occupy the first 30K words of primary storage.

3.4.1.9.2.2 Structure

3.4.1.9.2.2.1 Basic Structure

The basic software structure is illustrated in Figure 3.4.1.9.2-1. A core memory map is shown in Figure 3.4.1.9.2-2. As can be seen, this approach has no overlay segments. The rationale for this is as follows:

- With the present fixed base core loading, and a maximum transfer rate of 240K words/sec from the drum, no significant reduction in the total core loading could be made.

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• To implement a simple overlay structure will require the dedicated use of two high speed drum memories.

3.4.1.9.2.2.2 Jump List Management

The simulation software will be organized into four separate jump lists: A, B, C, and D. The occurrence of a program call in any particular jump list will be a function of four constraints:

- The effect of parallelism upon the module.
- The requirement for serial execution.
- Program iteration rate.
- Mission phases for which execution is required.

It is envisioned that the A, B, and C jump lists will contain all 20, 10 and 5/sec modules that execute in all, or almost all, mission phases. Low rate programs that must meet serial dependencies with these modules will be executed from the proper jump list. Inspection of the memory map shows that, where possible, all modules for the "A" jump list are grouped together, the "B" jump list modules are together, as are the "C" modules. Grouping this way will confine most memory contention to the data pool and subroutine area.

• The "D" jump list will consist of modules with low iteration rates, or those which are only executed in one or two phases, (e.g., ABES).

This will allow programs in extended storage to be executed by one CAU. Thus the high overhead of execution from extended storage is isolated in one CAU, which allows easier control of the loading.

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Extended storage will also contain the large, low access tables, (e.g., RADIO ALT. MAP) which have limited use during the simulation session. High access tables, (e.g., AERO DATA), will remain in primary storage to eliminate memory delays.

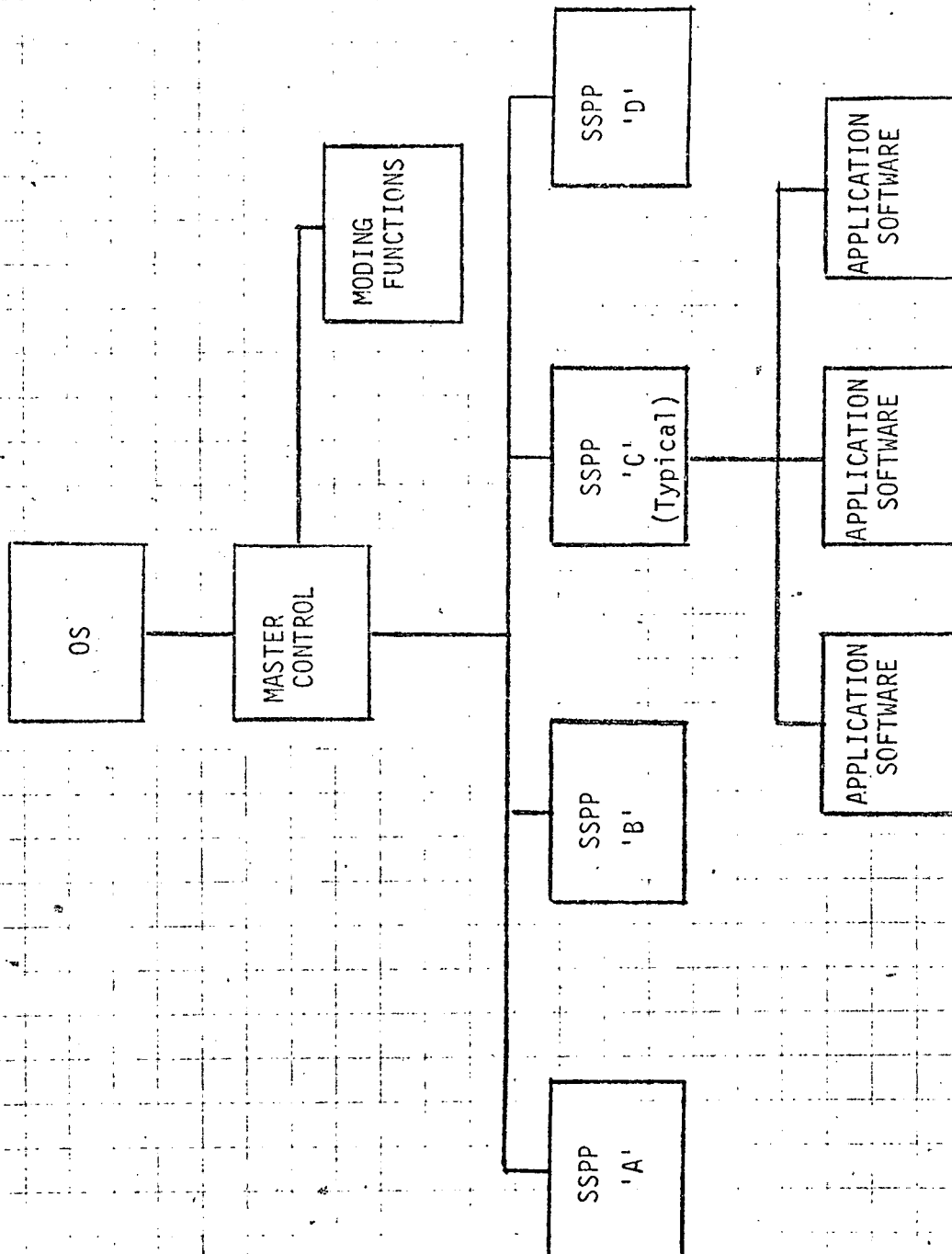


FIGURE 3.4.1.9.2-1

CONTROL STRUCTURE

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DATA POOL	CON- TROL	A 20/ sec	A 10/ sec	A 5/sec	B 20/ sec	B 10/ sec	B 5/sec	C 20/ sec	C 10/ sec	C 5/sec	D 2/sec	D 1/sec	D CRT	LOW ACCESS TABLES	HIGH RATE/FEW PHASE PROGRAMS D
--------------	--------------	-----------------	-----------------	------------	-----------------	-----------------	------------	-----------------	-----------------	------------	------------	------------	----------	-------------------------	--------------------------------------

↑
APPROX. PRIMARY/EXTENDED
STORAGE BOUNDARY

FIGURE 3.4.1.9.2-2

MEMORY MAP FOR UNIVAC 1110

3.4.1.9.3 Simulation Software Structure in Xerox Sigma 9

The Xerox Sigma 9 complex contains two configurations: Five Sigma 9's with 448K words of memory, and eight Sigma 9's with 512K words of memory.

3.4.1.9.3.1 General Requirements

The following requirements were made during the structure definition:

3.4.1.9.3.1.1 CPU Execution Rate

That each Sigma 9 is capable of executing 0.8 million instructions per second.

3.4.1.9.3.1.2 Memory Available to Each CPU

That all CPU's are capable of accessing all core memory within the configuration.

3.4.1.9.3.1.3 Memory Available to I/O System

That a part of the I/O system, under control of one CPU, can access all core memory within the configuration.

3.4.1.9.3.1.4 Background Processing

That the configuration has no requirement for background processing concurrent with simulation.

3.4.1.9.3.1.5 Operating System

That the simulation software structure will execute under direct control of either a standard vendor-supplied real-time operations system (e.g., CP-V). That the operating system is cognizant of the fact that there are multiple CPU's in the configuration.

3.4.1.9.3.1.6 External Interrupts

That upon the occurrence of an external interrupt, the operating system will pass control to a unique point in the simulation package.

3.4.1.9.3.1.7 Parallelism

That large portions of the simulation software can be executed in parallel.

3.4.1.9.3.1.8 Serial Execution

When the simulation software must be executed in a serial mode, that software will be executed in one, and only one, CPU. The computational demand does not exceed the limit of 3.4.1.9.3.1.1 above.

3.4.1.9.3.2 Simulation Software Structure

3.4.1.9.3.2.1 Basic Structure

The basic structure for the five CPU configuration is shown in Figure 3.4.1.9.3.-1. It will be obvious that the same structure can be used in the eight CPU configuration. A core memory map is shown in Figure 3.4.1.9.3-2.

As can be seen, this approach has no overlay segments. The basic rationale for this decision is as follows:

Due to the number of CPU's, the size of any particular overlay segment would not justify the number of high-speed mass storage devices that would have to be dedicated to each CPU.

3.4.1.9.3.2.2 Jump List Management

The simulation software will be organized into five separate jump lists: A, B, C, D, and E. The occurrence of a program call in any particular jump list will be a function of four constraints:

- The effect of parallelism upon the module.
- The requirement for serial execution.
- Program iteration rate.
- Mission phases for which execution is required.

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It is anticipated that the total execution demands will be spread evenly across all CPU's.

Inspection of the memory map shows that, where possible, the program load for each CPU will be contained in separate areas of memory.

This will confine most memory conflict to the data pool and subroutine areas.

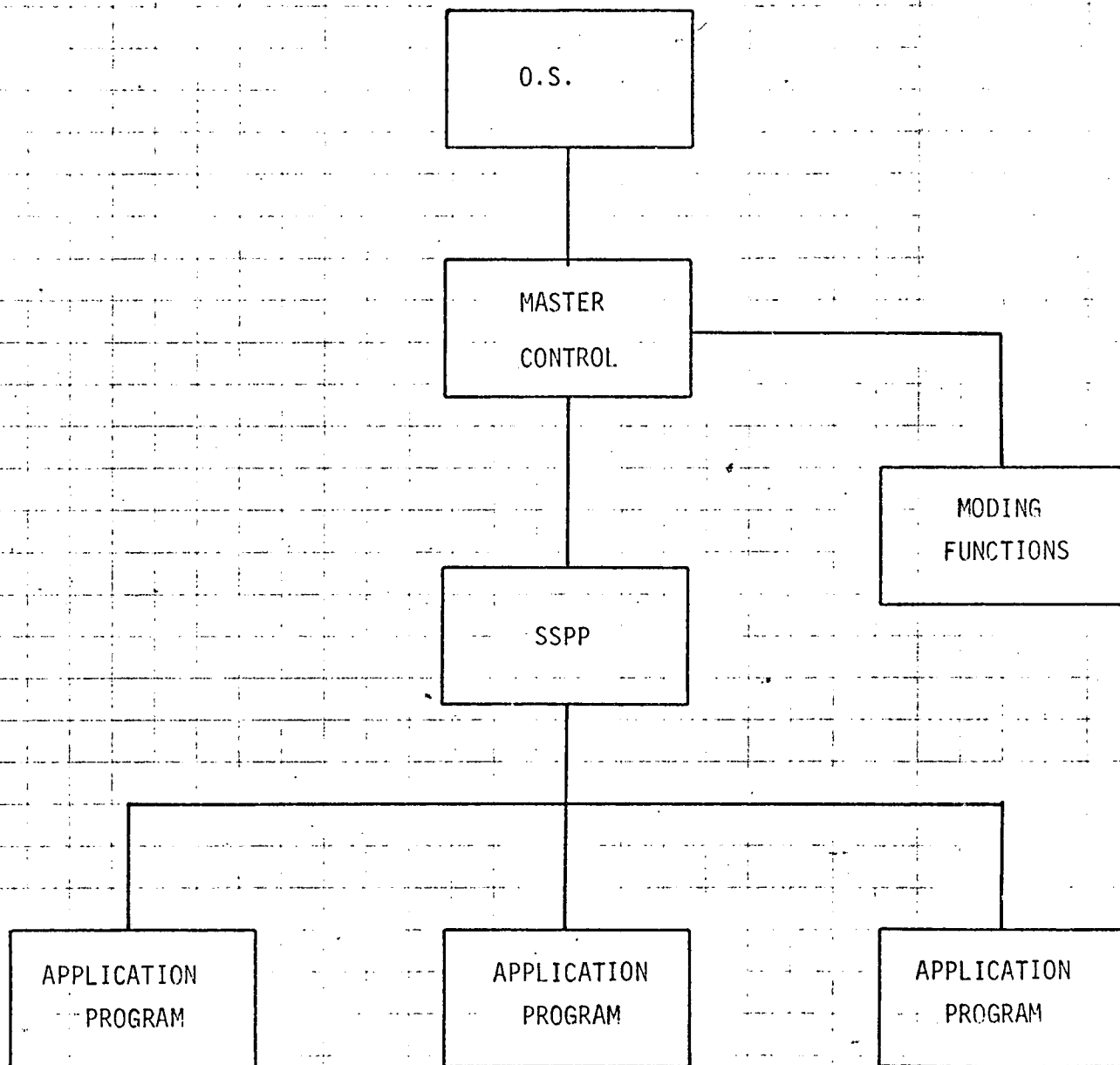


FIGURE 3.4.1.9.3-1

XDS Typical Software Structure (One CPU)

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HIGHER
MEMORY
ADDRESSES

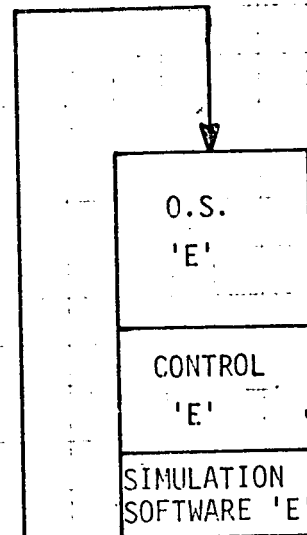
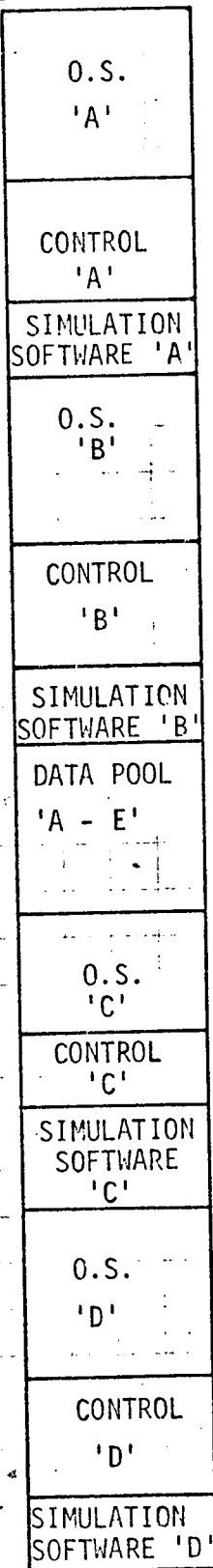


FIGURE 3.4.1.9.3-2

XDS Core Memory Map

3.4.1.9.4 Simulation Software Structure in the IBM Configuration

The IBM complex contains two configurations: one MP168 with 4 M bytes shared memory (referred to as the "A" complex), and one 168 with 2 M bytes of memory (referred to as the "C" complex).

Because of the existence of two non-symmetrical configurations, the IBM complex will require two structures, which will be referred to as the "A Structure" and the "C Structure".

3.4.1.9.4.1 General Requirements

The following requirements were made which apply directly to the structure definition:

3.4.1.9.4.1.1 CPU Execution Rate

Each CPU is capable of executing at least 4.0 million instructions per second.

3.4.1.9.4.1.2 Program/CPU Dependency

That a direct relationship can exist between a particular program and a particular CPU.

3.4.1.9.4.1.3 Operating System

That the operating system will be VS/2.2 or an upward compatible system.

3.4.1.9.4.1.4 Parallelism

Large portions of the simulation software can be executed in parallel.

3.4.1.9.4.1.5 Serial Execution

When the simulation software must be executed in a serial mode, that software will be executed in one, and only one, CPU. The computational demand does not exceed the limit of 3.4.1.9.4.1.1. above.

3.4.1.9.4.1.6 External Interrupts

Upon the occurrence of an external interrupt, the operating system will pass control to one unique entry point in the simulation software package.

3.4.1.9.4.2 Structure

3.4.1.9.4.2.1 Basic Structure

Neither the "A" or "C" structure utilize overlay segments.

The rationale for this is as follows:

- To implement a simple overlay structure will require dedicated use of one or more high speed drum memories per complex.

3.4.1.9.4.2.2 Basic "A" Structure

This structure is illustrated in Figure 3.4.1.9.4-1. A core memory map is shown in Figure 3.4.1.9.4-2.

The figure illustrates that all simulator control functions are performed in the "A" computer. The 'sync control' module inhibits SSPP execution until notified by master control that parallel execution may proceed. After the "B" SSPP has completed execution of a frame, the sync control module causes the simulation programs in the "B" computer to re-enter the wait state until again posted by master control.

3.4.1.9.4.2.3 "A" Structure Jump List Management

The simulation software will be organized into two separate jump lists, A and B. The occurrence of a program call in either jump list will be a function of four constraints:

- The effect of parallelism upon the module.
- The requirements for serial execution.

- Program iteration rates.
- Mission phases for which execution is required.

The "B" jump list will exist as a daughter task to the "A" jump list, eliminating memory protect conflicts. The two jump lists will be kept in sync via a "WAIT/POST" arrangement.

3.4.1.9.4.2.4 Basic "C" Structure

This structure is illustrated in Figure 3.4.1.9.4-3. The "C" structure is very similar to the "A" computer structure, the principal differences being the lack of the need to interface with another computer, and the fact that all programs will be executed by one SSPP.

3.4.1.9.4.2.5 "C" Structure Jump List Management

All of the simulation software will be executed by one jump list processor. The occurrence of a program call in the jump list will be a function of two constraints:

- Program iteration rate.
- The requirement for serial execution.

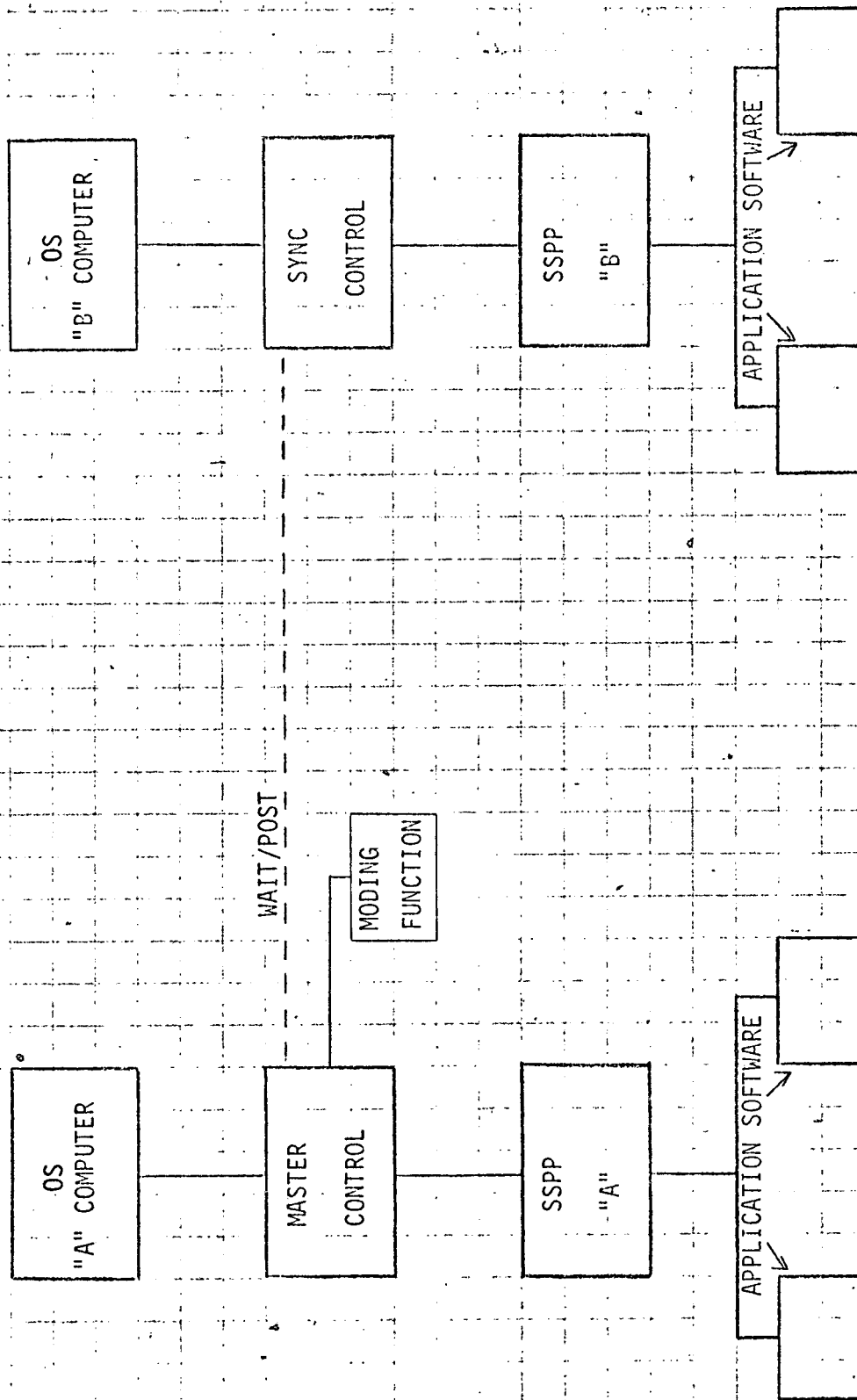


FIGURE 3.4.1.9.4-1

IBM "A" STRUCTURE

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DATA POOL	CONTROL SOFT- WARE	20/Sec	10/Sec	5/Sec	2/Sec	1/Sec	20/Sec	10/Sec	5/Sec	2/Sec	1/Sec
		"A"	"A"	"A"	"A"	"A"	"B"	"B"	"B"	"B"	"B"

FIGURE 3.4.1.9.4-2
IBM "A" STRUCTURE MEMORY MAP

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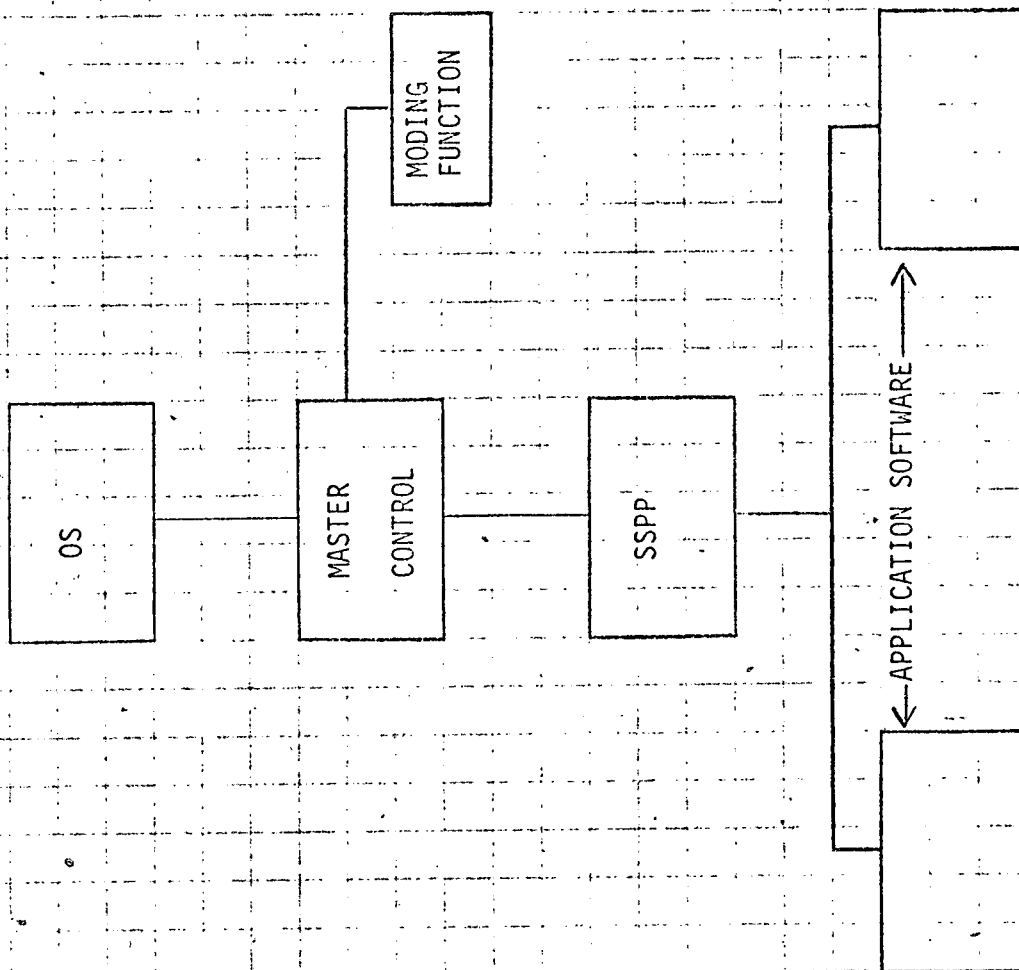


FIGURE 3.4.1.9.4-3

IBM "C" STRUCTURE

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3.4.1.9.5 Simulation Software Structure in the Control Data Configuration

The Control Data Configuration consists of one 7600 CPU, 65K words SCM, 512K words LCM.

3.4.1.9.5.1 General Requirements

The following requirements were made which apply directly to the structure definition:

3.4.1.9.5.1.1 CPU Execution Rate

The 7600 CPU is capable of executing 15.0 million instructions per second. This rate will be degraded to 12.0 million instructions per second by block transfers to/from SCM/LCM.

3.4.1.9.5.1.2 Operating System

The operating system will be Scope 2, or an upward compatible system.

3.4.1.9.5.1.3 External Interrupts

Upon the occurrence of an external interrupt, the operating system will pass control to one unique entry point in the simulation software package.

3.4.1.9.5.1.4 Operating System Size

The operating system will require the first 8K of SCM, and the first 65K of LCM.

3.4.1.9.5.2 Structure

3.4.1.9.5.2.1 Basic Structure

The basic software structure consists of multiple overlay segments rolled into SCM from LCM, using the block transfer instruction. The software structure presented in this section is applicable to either crew

station; hence the structure defined will be for Crew Station "X". A duplicate structure will be required for Crew Station "Y".

A core memory map is shown in Figure 3.4.1.9.5-1. As can be seen from the figure, the programs are grouped in one area of LCM; the "program commons" (data needed by only one program) are in another area; and the "global common" (data needed by two or more programs) is in a third area. (A program, P1, has program common C1; Program P2 has program common C2, etc. Program P2 does not need any data from any "C" except C2).

3.4.1.9.5.2.1.1 SCM Utilization

The simulation software will view SCM as if it has the format depicted in Figure 3.4.1.9.5-2.

Due to the computer architecture, the CPU executes at its fastest rate when both programs and data reside in SCM. It is the function of the "jump list sequencer and memory management" (JSMM) routine to move programs and their common area into SCM, execute the program, then move the program common back to LCM until needed again by the program.

3.4.1.9.5.2.1.2 LCM Utilization

LCM is used as a high-speed mass storage device. As noted above, the simulation programs, program common and global common reside in LCM and are rolled in from LCM to SCM prior to execution. After the program has executed, its program common is rolled back out to LCM. When all programs in a frame have executed, the global common is rolled out to LCM.

3.4.1.9.5.2.1.3 Typical Frame Execution

For illustrative purposes, let us assume that a computational frame contains two programs, "P1" and "P2", which have program commons "C1" and "C2"; the global common used is "GC".

The following events will occur during the frame execution:

- Occurrence of an external interrupt (e.g., 50 ms pulse) will cause the operating system to load SCM with the JSMM.
- The JSMM will move global common "GC" into SCM.
- JSMM will move program common "C1" into the program common area of SCM.
- JSMM will move program "P1" to the program area of SCM.
- JSMM causes program "P1" to be executed.
- At the conclusion of Program "P1" execution, the JSMM will move program common "C1" back to where it existed in LCM, and will move program common "C2" into the program common area of SCM.
- JSMM will move program "P2" into the program area of SCM.
- JSMM causes program "P2" to be executed.
- At the conclusion of Program "P2" execution, the JSMM will move program common "C2" back to where it existed in LCM.
- The JSMM senses the end of the frame and moves the global common "GC" back to where it existed in LCM.
- Its work completed for this frame, JSMM returns to the operating system until the next external interrupt.

3.4.1.9.5.2.1.4 Two Crew Station Operation

Since both crew stations will have the same basic structure, the principal difference between them is the external interrupt used to begin execution. It is envisioned that the central timing equipment will supply two 20 per second pulses spaced 25 milliseconds apart. Thus each crew station receives a 50 ms pulse for internal framing.

It may prove desirable to supply a "1 pulse per second" and "1 pulse per minute" for each crew station, the two pulses of each type separated by 25 milliseconds. This will allow correct synchronization when integrated with MCC or another complex.

3.4.1.9.5.2.2 Jump List Management

All of the simulation programs will be executed from one jump list, which is made up of 20 frames. The occurrence of a program call in the jump list will be a function of two constraints:

- The requirement for serial program execution.
- Program iteration rate

Each entry in the jump list will consist of five elements:

- Program address in LCM
- Program length
- Program common address in LCM
- Program common length
- Flags indicating for which mission phases the program is to execute.

The JSMM routine will check the mission phase flags prior to moving the program or its common, eliminating the movement overhead if the module is not being executed.

The first and last entry in the jump list will contain flags to the JSMM indicating the LCM location and length of the global common area.

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P1	P2	P3	P4	P5	...	P _N	C1	C2	C3	C4	C5	...	C _N	GC
----	----	----	----	----	-----	----------------	----	----	----	----	----	-----	----------------	----

PROGRAM AREA

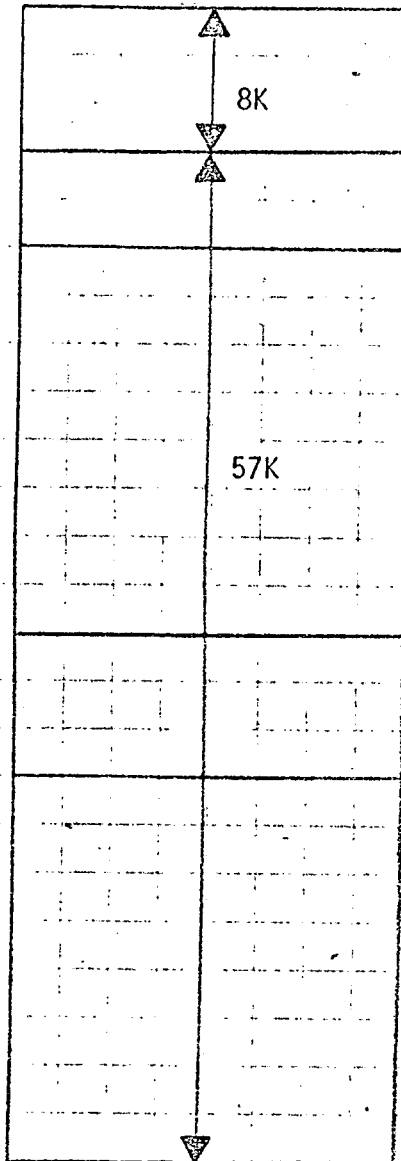
PROGRAM COMMON

GLOBAL COMMON

FIGURE 3.4.1.9.5-1

CDC LCM MEMORY MAP OF SIMULATION SOFTWARE

0



Operating System

Jump List Sequencer and
Memory Management

Program Execution Area

Program Common Swap Area

Global Common Swap Area

FIGURE 3.4.1.9.5-2
SCM LAYOUT

3.4.2 Data Management System (DMS)

The DMS as depicted in Figure 3.4.2-1 will provide the maintenance and status capabilities, through an automated process, of the detailed hardware and software configuration of the SMS.

The focal point of the DMS is the Generalized Data Base Management System (GDBMS). The GDBMS is a computer manufacturer's system (CODASYL Standard) data base management system. The GDBMS should provide the following major features:

Data Structure

Data structure is the view of the data as seen by the user of the system and excluding any details of storage techniques used which are covered in a separate section. An understanding of the data structure of either kind of data base system is essential to a good understanding of its capabilities.

Data structure levels are identified as item, group, group relation, entry (record), file and data base. The definition of a data structure is referred to throughout the report as a schema. It is also possible in some systems to have several sub-schemas which are subsets of the schema.

Data Definition

The language and/or tabular formats used to define a schema representable within the system's capability to handle data structures.

Interrogation

Interrogating a data base is a process of selecting and extracting some part of the whole data base for display, usually in a hard copy printed form. One section of the interrogation function defines how the part is selected. The second part covers how operations such as computation, sorting and formatting may be performed on the selected part. The concept of interrogation is an

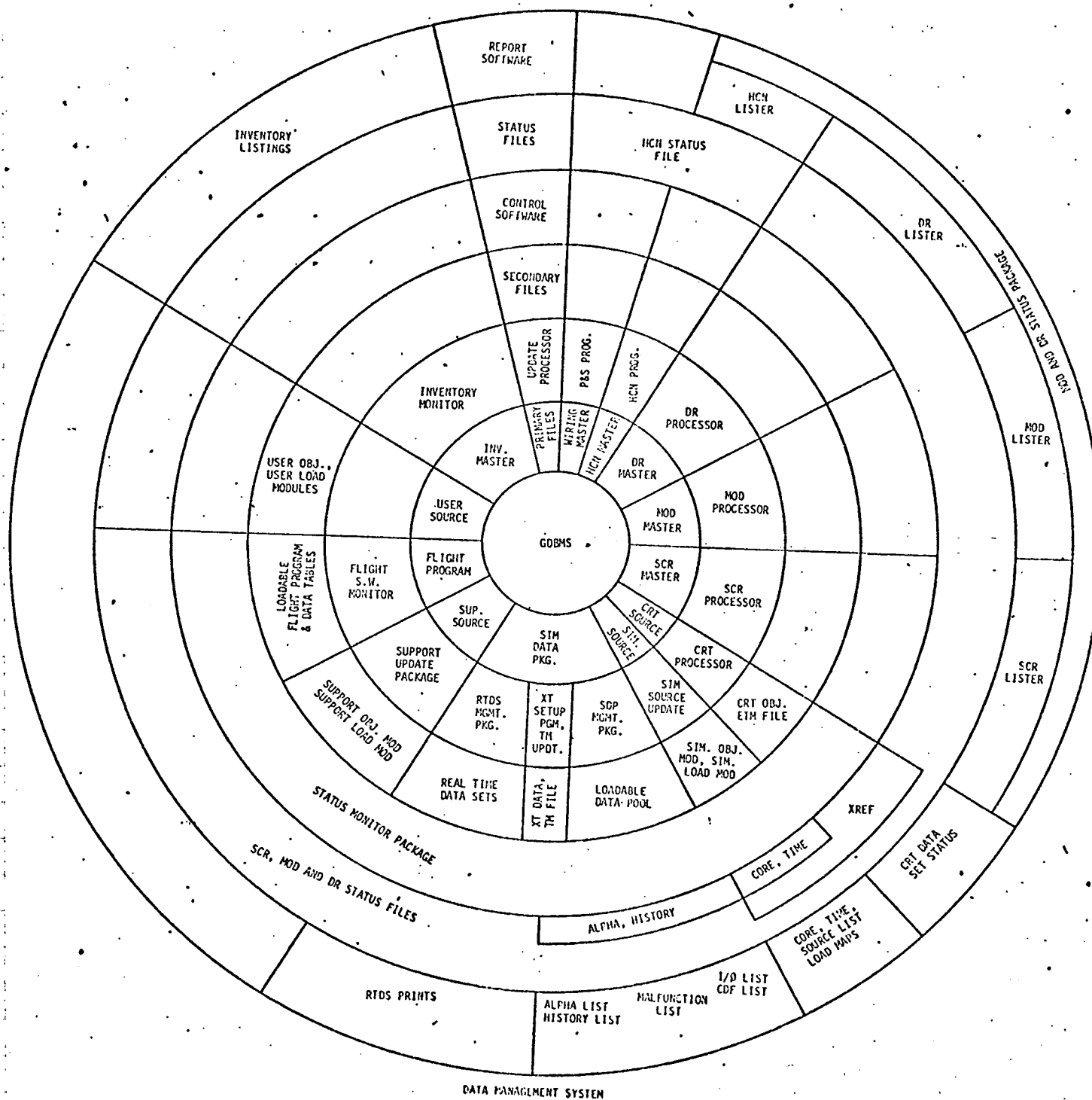


Figure 3.4.2-1

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intrinsic self-contained capability. The implication is that the user is able to formulate a query in the language of the system without detailing the sequence of steps used to access the data base and extract the information.

Availability of the interrogation function implies that a built-in processing algorithm for the function is provided by the system. In the simplest case, the processing algorithm is that of sequentially searching a stored file, copying out records which satisfy some conditional expression, and building up a report based on the data contained in these records. There are many degrees of sophistication even within the framework of the basic sequential search algorithm. Other processing algorithms cause the file to be accessed to obtain the required information, using various techniques which avoid a sequential search.

Update

Updating a data base is a process of changing the value content of some part of the data base. It excludes restructuring of the data which would cause a modification to the stored data definition. Update is a process somewhat analogous to interrogation in that some part of the data base must first be selected. In most self-contained systems, the selection facilities are modelled on those used in the interrogation function. However, once the part is selected, it is changed in some defined way rather than displayed in a report.

Update is intrinsically a self-contained capability. It also implies a built-in processing algorithm, but the possible ways of implementing it are even more varied than for interrogation. In some systems, both update and interrogation can be performed during the same sequential pass of a file in the data base.

Creation

An important preliminary to the creation function is that of data definition. It is necessary to provide a set of records to form the initial instance of a file. Other functions are data validation, security specification and control over media type. Data base creation is considered to be one of the important functions for the data administrator. Creation may imply a built-in processing algorithm as for interrogation and update, or it may have to be programmed in a conventional sense. In many cases it is a use of the updating function applied to a null file.

There is no clear division here between self-contained systems and host language systems. Some self-contained systems do require a programmed approach to file creation. This implies that providing the initial instance of the file is a function which has to be programmed using facilities other than those provided by the system.

Programmer Functions

Programmer functions are defined as host language capabilities. They are functions upon which a programming user may call when writing a program in a host language. The most important programmer function statements are those which permit him to initiate data transfers between the stored data base and high speed memory. Other statements may be provided to allow him to issue file control statements such as open, close and hold.

Any function considered to be in the domain of the data administrator, even though its use may be on the level of the programmer, is not considered in this section.

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Data Administrator Functions

The data administrator is an individual responsible for a data base. His role is identified to some extent in both host language and self-contained systems. Such functions include monitoring system operation, preservation of system integrity and security, and providing for restructuring the data base to accommodate new record types or new items. Some of the data administrator's functions may have to be performed with a programmer level language in some systems. In this case the designation of a function as an administrator function is subjective.

Storage Structure

Each level of the data structure has a stored representation which is referred to as the storage structure. The file level storage structure defines how entries are stored in physical blocks to form the stored representation of the file. This level is often dictated by the input/output control system, which in third generation operating systems has been given the name of data management system. File level storage structures include such techniques as indexed sequential and other ways of storing a file and data about it to facilitate access to its contents.

The entry level storage structure varies more widely among systems and it defines how groups or items are represented in storage to form the stored representation of an entry. Sometimes all entry data is stored contiguously in low speed memory, but in some systems groups are mapped into segments where the segments in an entry may be stored in different locations in low speed memory. Finally item level storage structure usually reflects the storage modes of the machine although systems exercise different levels of control in their data structure over the mapping of items into storage structure formats.

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The following paragraphs describe the functions and capabilities that the Data Management System of the SMS should provide:

3.4.2.1 Simulation Source Management System

3.4.2.1.1 Master Domain

3.4.2.1.1.1 Files

CRT Source Modules - A library will be maintained containing one member for every CRT source program in compressed form. This library would contain test areas for testing new page programs as they are being developed.

Simulator Software Source - A library will be maintained containing one member for every operational program in compressed source form. Strict coding conventions will be applied to insure the utilization of the self documenting features of a source language to its fullest extent.

3.4.2.1.1.2 Processors

CRT Off-Line Processor - A processor will be provided to update CRT source programs and compile them into an object library accessible by the real-time CRT processor. Event time monitor information will also be provided to the CRT on-line processor through this program. Additional information will be passed to the Status Monitor Package and the cross reference data set will be modified for every CRT page which undergoes a permanent source update. Source listings which result will be passed to a simulator source listing data set.

Simulator Source Update Processor - The facilities will be available to make program changes both permanent and temporary to operational programs. Object data sets will result which will later be meshed with other routines through a load generation process. Source listings which result will be passed to a Simulator Source Listing data set.

3.4.2.1.2 Control Domain

3.4.2.1.2.1 Files

CRT Object Program Library - A library will be maintained providing one member for each CRT page in operational or test status. This library will

be of a direct access nature to permit fast access by the CRT on-line processor.

ETM File - This file will provide the real-time CRT processor with the information needed to generate the event time monitor and tripped circuit breaker displays. This file will be of a direct access nature to permit fast access by the CRT real-time processor.

Simulator Software Object - An object library which will maintain at least one object copy of every operational program. The modules will be accessed from this library by the program which builds loadable modules.

Simulator Source Listings - Source listings for all simulator software will be maintained in compressed form that they may be called out for listing at any time from a remote site or the central processor station.

3.4.2.1.2.2 Processors

Core Loading Monitor Program - A program will be provided to analyze the output of the loader program and give edited printouts, including module lengths in decimal and other special data pertinent to the task structure.

Status Monitor Package - A group of programs will be provided to update, according to the type of update, the SCR, Mod, and DR status file. Programs in this package will be called directly from processors in the Master Domain.

Time Loading Monitor Program - The time loading monitor program will be a special real-time executive which will extract timing information from individual routines as they run and store this information in the Time Loading Status File for future reference.

3.4.2.1.3 Report Domain

3.4.2.1.3.1 Files

Core Loading Status File - A file will be maintained which contains all core loading information as provided by the Core Loading Monitor Program.

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This data will consist of program names, size, and overlay segment if applicable.

Cross Reference (XREF) Data Set - A data set containing one member for each source module and each CRT source program will exist denoting all SDP terms used by that program in its current status. This information is provided by the Simulator Source Update Package and the CRT off-line processor.

SCR, Mod, and DR Status File - A file will be maintained to describe all SCR's, Mods and DR's as to their status and effect on simulation. Information from this file will be unloaded to permanent storage when a given time period has elapsed after final incorporation into a training simulator load.

Time Loading Status File - A file will be kept current containing timing information on every simulator software module.

3.4.2.1.3.2 Processors

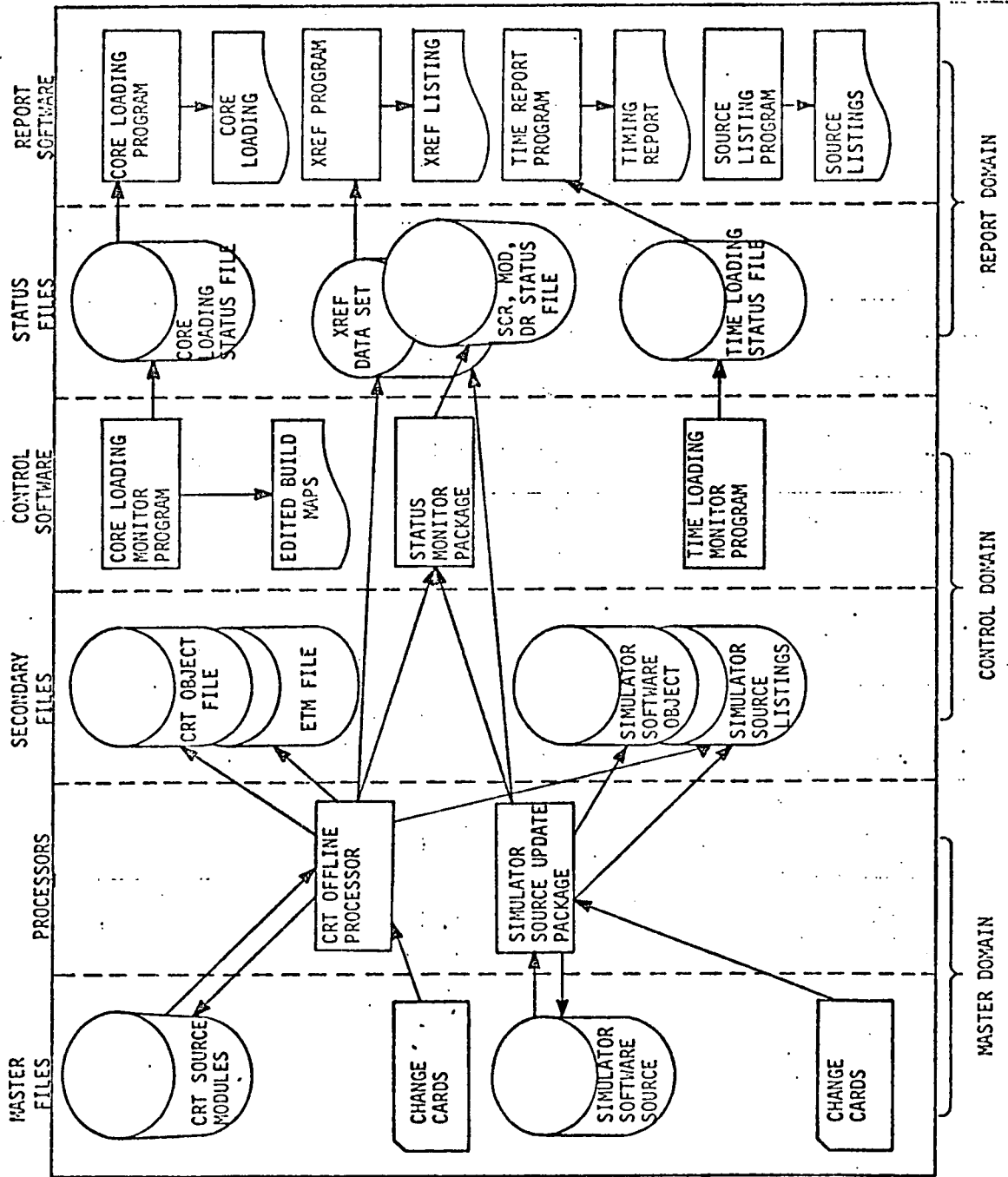
Core Loading Program - A program will be developed to provide complete core utilization reports from the Core Loading Status File.

XREF Program - A program will be maintained to provide a cross reference of all terms used in the simulator source by term and by program. An additional facility will provide a printout of all terms not used but maintained in the SDP.

Time Report Program - A method will be provided for generating automated time reports from information contained in the Time Loading Status File.

Source Listing Program - A program will be maintained to selectively print source listings from the Simulator Source Listing File with options for printing or suppressing assembly language printouts, cross references, maps, etc.

3.4.2.1 Simulation Source Management System



3.4.2.2 Simulation Data Pool Management System

3.4.2.2.1 Master Domain

3.4.2.2.1.1 Files

Configuration Data File - Sufficient information will be contained in the Configuration Data File to describe completely every term referenced by the real-time simulation source modules. This information will include, but not limited to, description, range or value, units, scaling (fixed point), array information, data type and precision.

Simulator Software Source - A library will be maintained containing one member for every operational program in compressed source form. Strict coding conventions will be applied to insure the utilization of the self documenting features of a source language to its fullest extent.

3.4.2.2.1.2 Processors

Simulation Data Pool Management Package - Processors will be developed to generate, from the configuration data file and change cards, updated History and Alpha files. In addition, a processor will be developed to generate the necessary data pools in the form of source modules, which will be added to the Simulator Software Source File. Appropriate information will be passed to the Status Monitor Package to provide a history of all changes made.

3.4.2.2.2 Control Domain

3.4.2.2.2.1 Files

Alpha File - Configuration Data File items pertaining to each data pool term are contained in the Alpha file. This data will be sufficient to provide linkage to the data pool for source programs. The term records are in alphabetical order.

3.4.2.2.2.2 Processors

Status Monitor Package - A group of programs will be provided to update, according to the type of update, the SCR, Mod, and DR status file. Programs in this package will be called directly from processors in the Master Domain.

3.4.2.2.3 Report Domain3.4.2.2.3.1 Files

History File - The History file will contain comparable information to the Alpha file however it will be arranged in core order rather than alphabetical order. Each location in each data block will be accounted for.

SCR, Mod and DR Status File - A file will be maintained to describe all SCR's, Mods and DR's as to their status and effect on simulation. Information from this file will be unloaded to permanent storage when a given time period has elapsed after final incorporation into a training simulator load.

3.4.2.2.3.2 Processors

SDP Report Generation Software - Sufficient software will be developed to generate reports including, but not limited to, the following:

Malfunction Lists

I/O Term Lists

CDF List

History List

Alpha List

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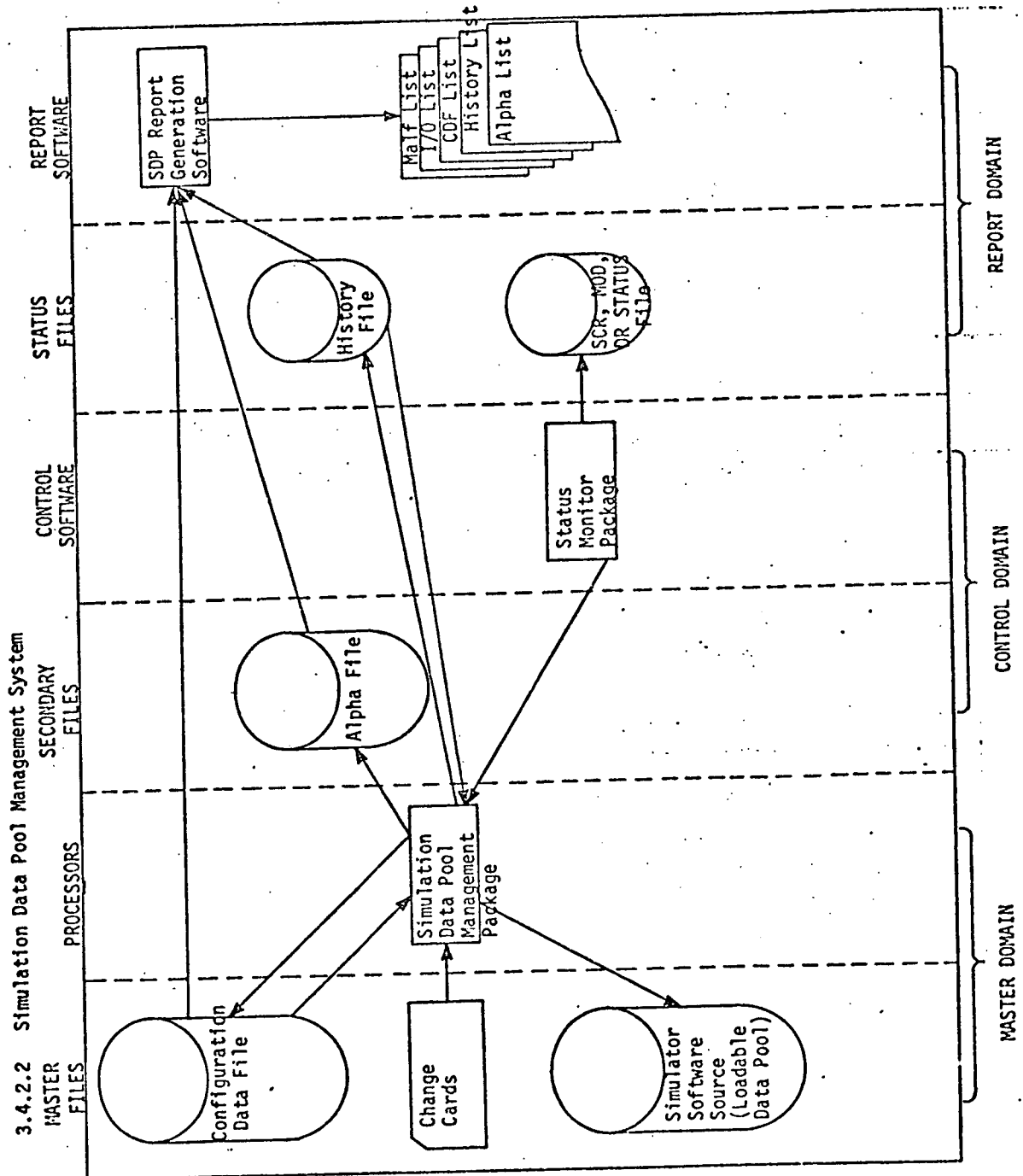
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3.4.2.3 Simulation Data Package Management System

3.4.2.3.1 Master Domain

3.4.2.3.1.1 Files

Simulation Data Package - The simulation data package contains all data received from outside sources. This data will be used for, but not limited to, creating the following real-time data sets:

Reset

Flight Computer Resets

Aero Tables

Ephemeris Data

Visual Data (Film Constants)

3.4.2.3.1.2 Processors

Simulation Data Processor Package - A separate processor program will be developed for generating each real-time data set to be derived from the Simulator Data Package. Status information will be passed to the Status Monitor Package. Update capability will be provided to change any data in the package as new data is received.

3.4.2.3.2 Control Domain

3.4.2.3.2.1 Files

Real-Time Access Data Files - The extent to which real-time data sets will be provided will be determined by the requirements of the simulator task.

3.4.2.3.2.2 Processors

Status Monitor Package - A group of programs will be provided to update, according to the type of update, the SCR, Mod, and DR status file. Programs in this package will be called directly from processors in the Master Domain.

3.4.2.3.3 Report Domain3.4.2.3.3.1 Files

SCR, Mod and DR Status Files - A file will be maintained to describe all SCR's, Mods and DR's as to their status and effect on simulation. Information from this file will be unloaded to permanent storage when a given time period has elapsed after final incorporation into a training simulator load.

3.4.2.3.3.2 Processors

Real-Time Data Set Display Package - Sufficient display programs will be developed for formatting printouts of all real-time data sets.

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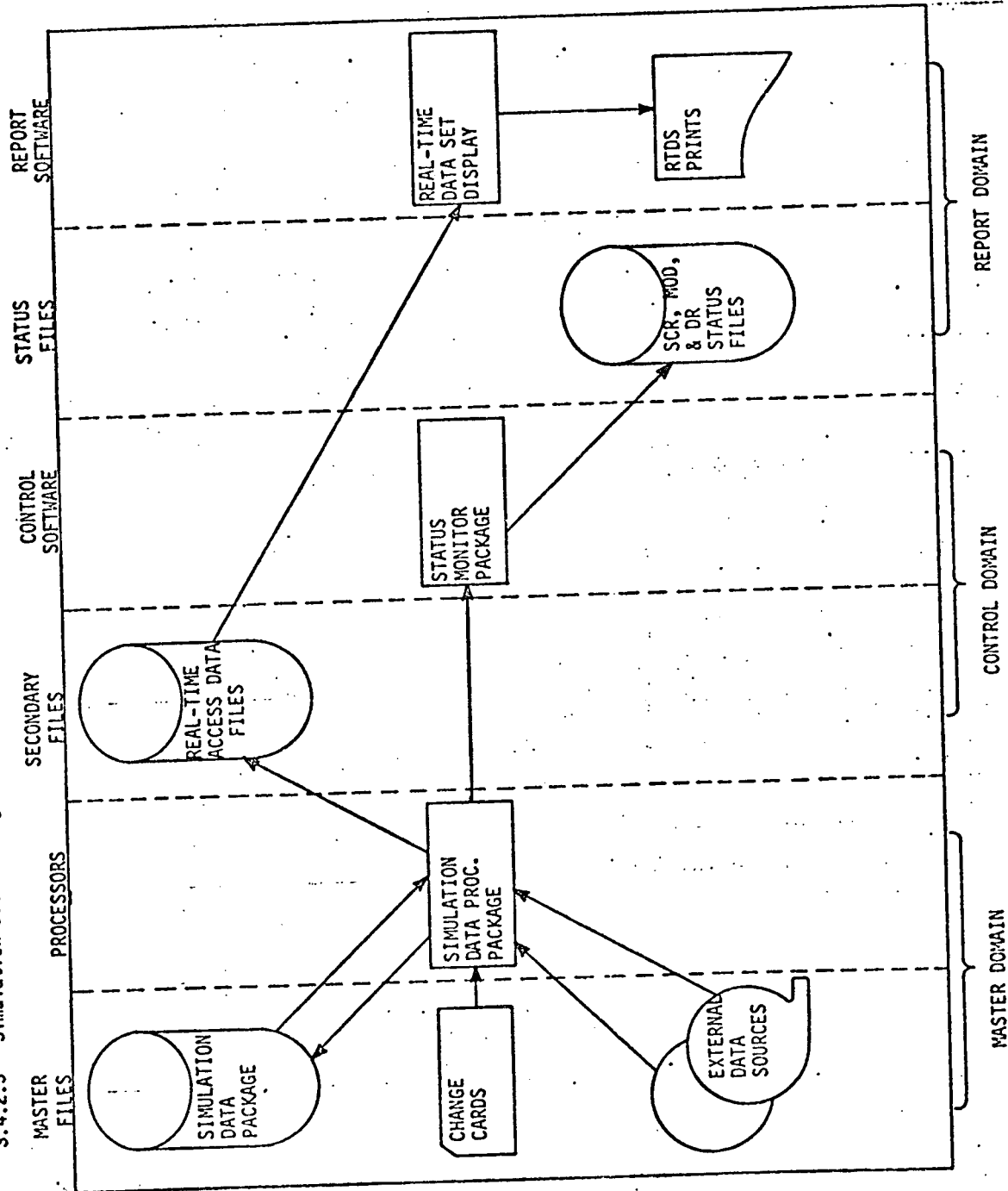
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3.4.2.3 Simulation Data Package Management System



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3.4.2.4 Support Software Management System

3.4.2.4.1 Master Domain

3.4.2.4.1.1 Files

Support Software Master Source - All utility support source not pertaining to Sections 3.4.2.1, 3.4.2.2 or 3.4.2.3 will be contained in Support Software Master Source Library. Software in this library is controlled source, changeable through standard SCR procedures.

3.4.2.4.1.2 Processors

Support Source Update Processor - The capability will exist within the support source update processor to update existing source, create appropriate object modules and communicate appropriate information to the Status Monitor Package.

3.4.2.4.2 Control Domain

3.4.2.4.2.1 Files

Support Software Load Modules - All support software will be kept in a load module library ready for execution with no pre-processing required.

Support Software Modules - Individual subroutines may be placed in an object module library for later incorporation into a load module when combined with other subroutines.

3.4.2.4.2.2 Processors

Status Monitor Package - A group of programs will be provided to update, according to the type of update, the SCR, Mod, and DR status file. Programs in this package will be called directly from processors in the Master Domain.

3.4.2.4.3 Report Domain

3.4.2.4.3.1 Files

SCR, Mod and DR Status Files - A file will be maintained to describe all SCR's, Mods and DR's as to their status and effect on simulation. Information

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from this file will be unloaded to permanent storage when a given time period has elapsed after final incorporation into a training simulator load.

3.4.2.4.3.2 Processors

Not applicable.

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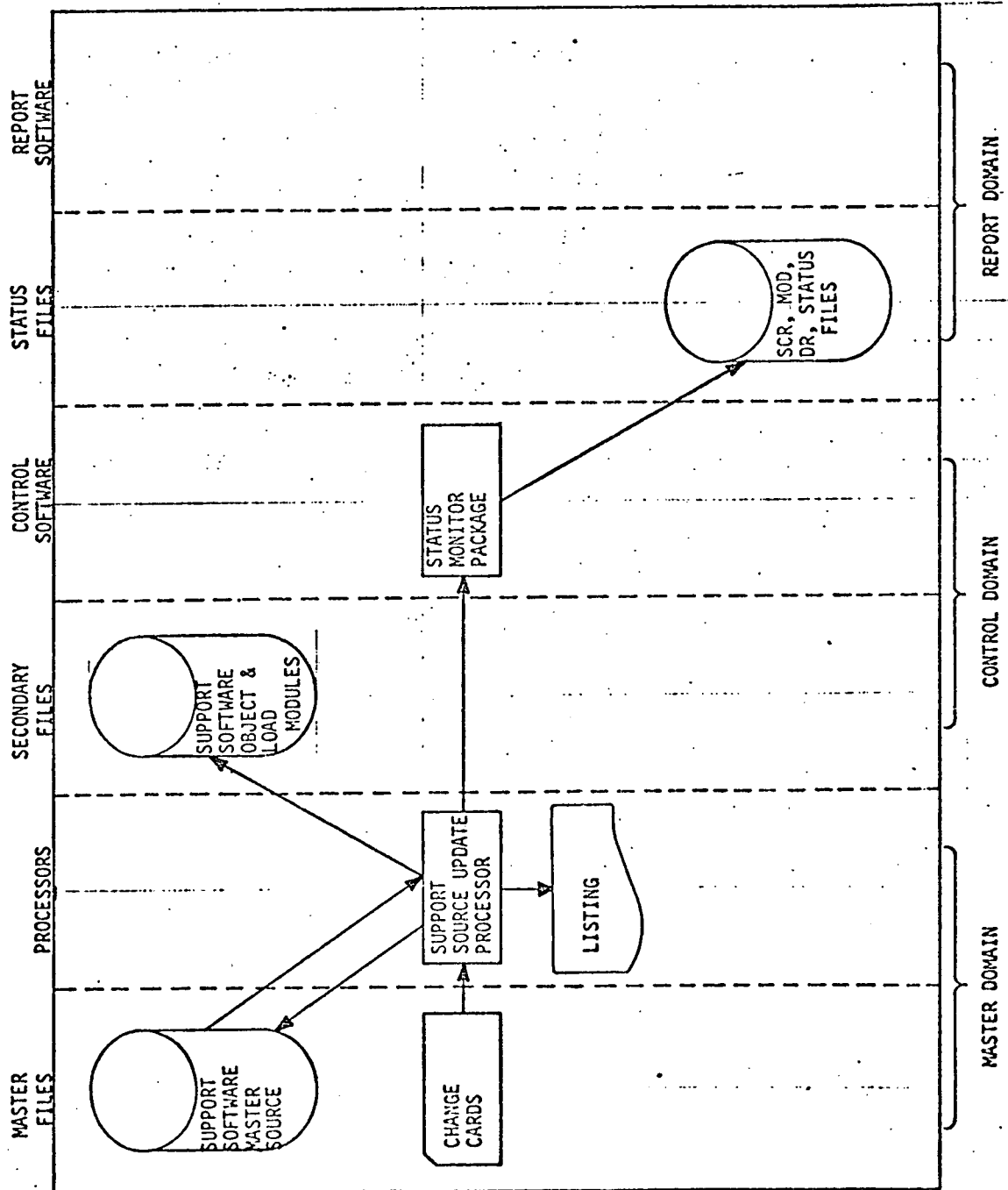
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3.4.2.4 Support Software Management System



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3.4.2.5 Flight Program Management System

3.4.2.5.1 Master Domain

3.4.2.5.1.1 Files

Flight Program Master Source - Flight Program masters are to be kept in a library which contains one program per member. Any additional flight program source information, such as data tables, will be kept in the same data set as members.

3.4.2.5.1.2 Processors

Flight Program Update Processor - A program will be provided to make updates to the stored flight program sources, produce loadable flight programs and any other flight information required for real-time operation exclusive of reset, which will be handled elsewhere. Information will be passed directly to the Status Monitor Package describing the changes made to the flight source.

3.4.2.5.2 Control Domain

3.4.2.5.2.1 Files

Loadable Flight Program - Flight programs will be stored in a library accessible to on-line operation on a read only basis.

Real-Time Flight Program Data Sets - Data sets which are necessary for real-time flight program operations will be provided. This does not include reset data, which is part of the Real-Time Data Set Package.

3.4.2.5.2.2 Processors

Status Monitor Package - A group of programs will be provided to update, according to the type of update, the SCR, Mod and DR status file. Programs in this package will be called directly from processors in the Master Domain.

3.4.2.5.3 Report Domain

3.4.2.5.3.1 Files

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SCR, Mod, and DR Status Files - A file will be maintained to describe all SCR's, Mods and DR's as to their status and effect on simulation. Information from this file will be unloaded to permanent storage when a given time period has elapsed after final incorporation into a training simulator load.

3.4.2.5.3.2 Processors

Not Applicable

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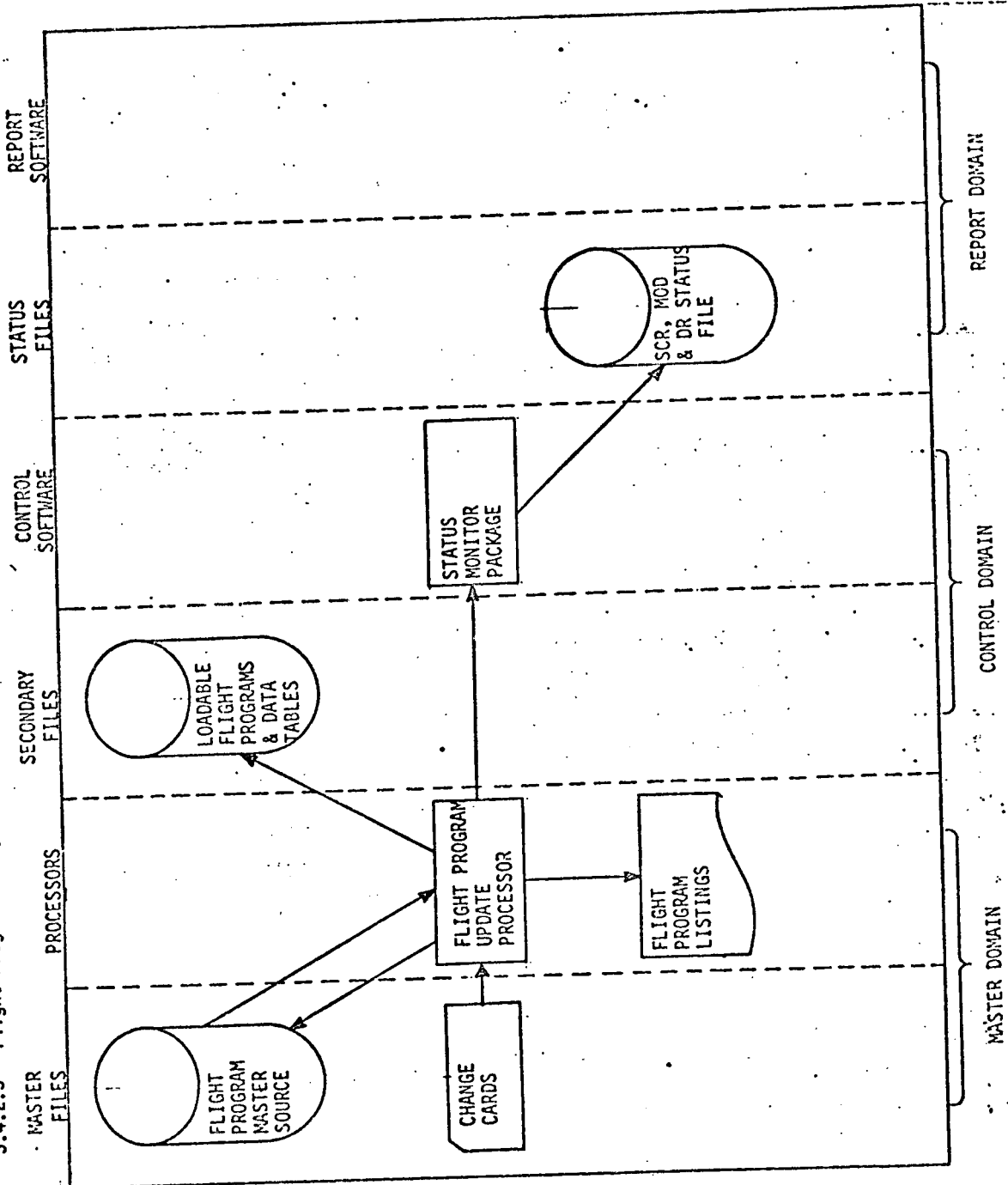
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3.4.2.5 Flight Program Management System



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3.4.2.6 Supply Inventory

The Supply Inventory System is a computer based system which will control the supply inventory, providing up-to-date reports with a minimum amount of delay.

3.4.2.6.1 Master Domain

3.4.2.6.1.1 Master Files

The two master files associated with the supply inventory are the Supply Inventory Master and the Transaction Master. The Supply Inventory Master file will contain the basic information on the items in the inventory such as: manufacturer part number, control number, part name, description, stockroom location, minimum stock level, maximum stock level, quantity on hand, unit cost, and if the item is available from Federal Stock.

The Transaction Master will contain all the transactions occurring against the inventory. The information will contain such information as: control number, type of transaction, quantity, disposition and total cost of transaction.

3.4.2.6.1.2 Processors

Two types of data are input the Supply Inventory Processor (SIP): basic inventory data designating stock items which comprise the inventory base, and quantity change data (transactions), which will include item issue records, receipts, re-order confirmations, and stock returns. This data would be input via CRT's or card.

The SIP will process the inputs against the Supply Inventory Master and Transaction Master files and will generate the re-order and excess reports.

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Once the quantity-on-hand of an item drops below the stated minimum, it is put on the re-order report. Since some items are available from Federal Stock while others are not, one of two actions will be performed. For all items available from Federal Stock, the re-order form will be printed and a re-order transaction will be generated. For all items not available from federal stock, the re-order and re-order transaction must be generated manually.

3.4.2.6.2 Control Domain

3.4.2.6.2.1 Secondary Files

None

3.4.2.6.2.2 Control Software

None

3.4.2.6.3 Report Domain

3.4.2.6.3.1 Status Files

None

3.4.2.6.3.2 Report Software

The Supply Inventory Report Generator will generate three types of reports: inventory listing, transaction listing, and current usage. These reports are generated from the Supply Inventory Master and Transaction Master files. These reports may be by manufacturer part number, control number, part name/description or any other meaningful order. The reports generated may be listings of the entire file or of a specified portion of it.

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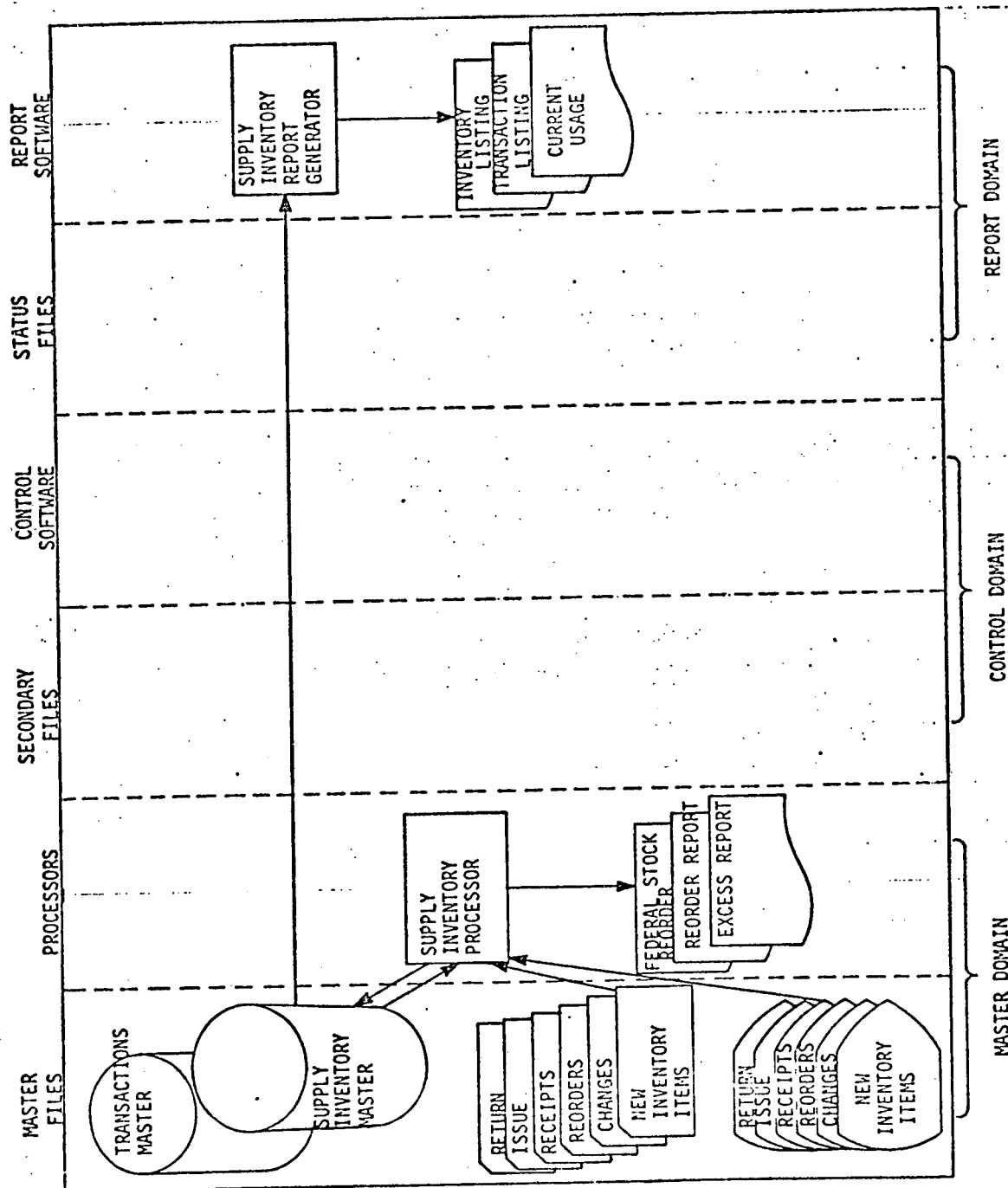
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3.4.2.6 Supply Inventory



3.4.2.7 User Software

User software is that software not directly associated with the simulation or in support of the simulation.

3.4.2.7.1 Master Domain

3.4.2.7.1.1 Master Files

The master files for the user software will consist of modules of source code. The source may be in any programming language supported by the vendor.

3.4.2.7.1.2 Processors

The processors associated with user software are all vendors supplied and include an update processor to maintain the source modules, language processors to compile the source, and a linking loader to build the load modules. The input to the update processor, either to create a new source module or modify an existing source module, can come from CRT's or cards. In addition to the generation of the object modules, the language processors will also generate listings of the source.

3.4.2.7.2 Control Domain

3.4.2.7.2.1 Secondary Files

The files associated with the control domain are the object modules generated by the language processors, and the executable load modules generated from the object modules by the linking loader.

3.4.2.7.2.2 Control Software

None

3.4.2.7.3 Report Domain

3.4.2.7.3.1 Status Files

None

3.4.2.7.3.2 Report Software

None

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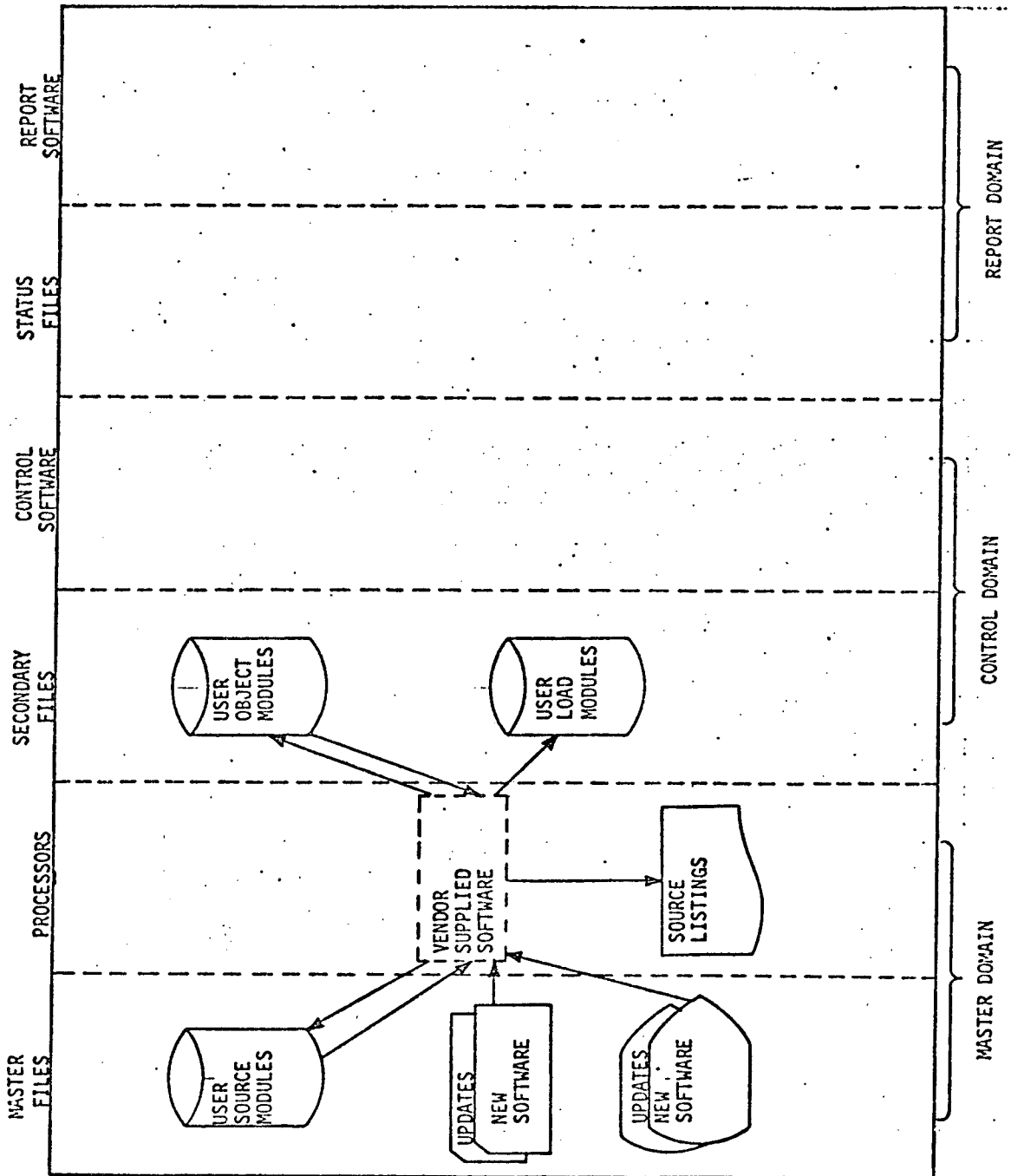
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3.4.2.7 User Software



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3.4.2.8 Discrepancy Reports

The Discrepancy Report System will provide a means of monitoring the status of discrepancy reports (DR's).

3.4.2.8.1 Master Domain

3.4.2.8.1.1 Master Files

The DR Master file will contain all the pertinent information associated with each DR, such as DR number, date written, simulator effected (MBTS, FBTS), system effected, type of DR, DR statement, person who wrote the DR, person assigned the DR status, SCR's associated with each DR, etc.

The System Responsibility file will contain the name of the responsible person for each system of each simulator.

3.4.2.8.1.2 Processor

The DR will be put into the system via a CRT by the originating individual. At this time the DR Processor will assign a number to the DR and assign the DR to the person responsible for the effected system. Any changes to the DR or system responsibility will also be entered via a CRT. The DR status and associated SCR's will be maintained with input from the DR, Mod, and SCR Status file.

3.4.2.8.2 Control Domain

3.4.2.8.2.1 Secondary Files

None

3.4.2.8.2.2 Control Software

None

3.4.2.8.3 Report Domain

3.4.2.8.3.1 Status Files

DR, Mod, and SCR Status File

The information contained in the DR, Mod, and SCR Status File

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(See Section 3.4.2.1.1.1) is incorporated into the DR master file for use in generating the DR Status Report.

3.4.2.8.3.2 Report Software

The reports generate utility data in the DR Master and System Responsibility files. The reports may be concerned with the entire file or a specified portion of it. Three reports are generated by the system: system responsibility, DR listing, and DR status. The system responsibility report is a listing of the System Responsibility file and may be generated by system, simulator or individual. The DR listing will contain a list of all associated SCR numbers which may be generated for specified DR's. This listing would serve as the documentation of a DR that has been cleared and is no longer required in the system. The DR status report gives the ability to track DR's through the system. DR's could be separated by status, system, responsible individual, etc. Status information on specific DR's may be requested from CRT's and displayed in real-time.

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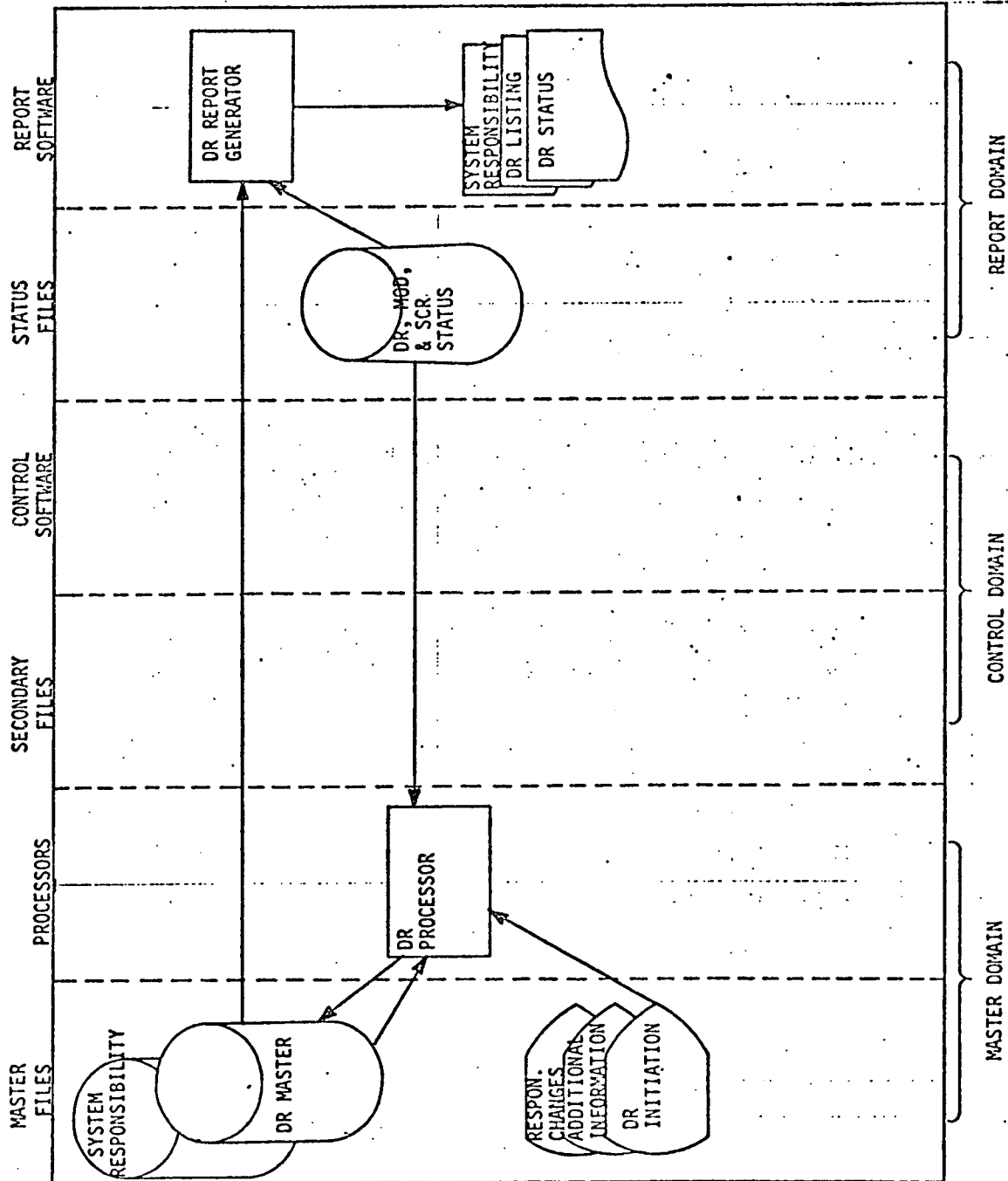
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3.4.2.8 Discrepancy Reports



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3.4.2.9 Modifications

This system will provide a means of monitoring the status of all modifications (mods) within the system.

3.4.2.9.1 Master Domain

3.4.2.9.1.1 Master Files

The Modification Master file will contain all pertinent information associated with each mod. This information shall include: mod number, description, schedule dates, DR's, and SCR's associated with each mod.

3.4.2.9.1.2 Processors

New mods and changes to existing mods, such as schedule dates, will be input to the Modification Processor via card or CRT. The mod status and associated SCR's will be maintained with inputs from the DR, Mod, and SCR Status file.

3.4.2.9.2 Control Domain

3.4.2.9.2.1 Secondary Files

None

3.4.2.9.2.2 Control Software

None

3.4.2.9.3 Report Domain

3.4.2.9.3.1 Status Files

The information contained in the DR, Mod, and SCR Status file (See Section 3.4.2.1.1.1) is incorporated into the Modification Master file for use in generating the Mod Status Report.

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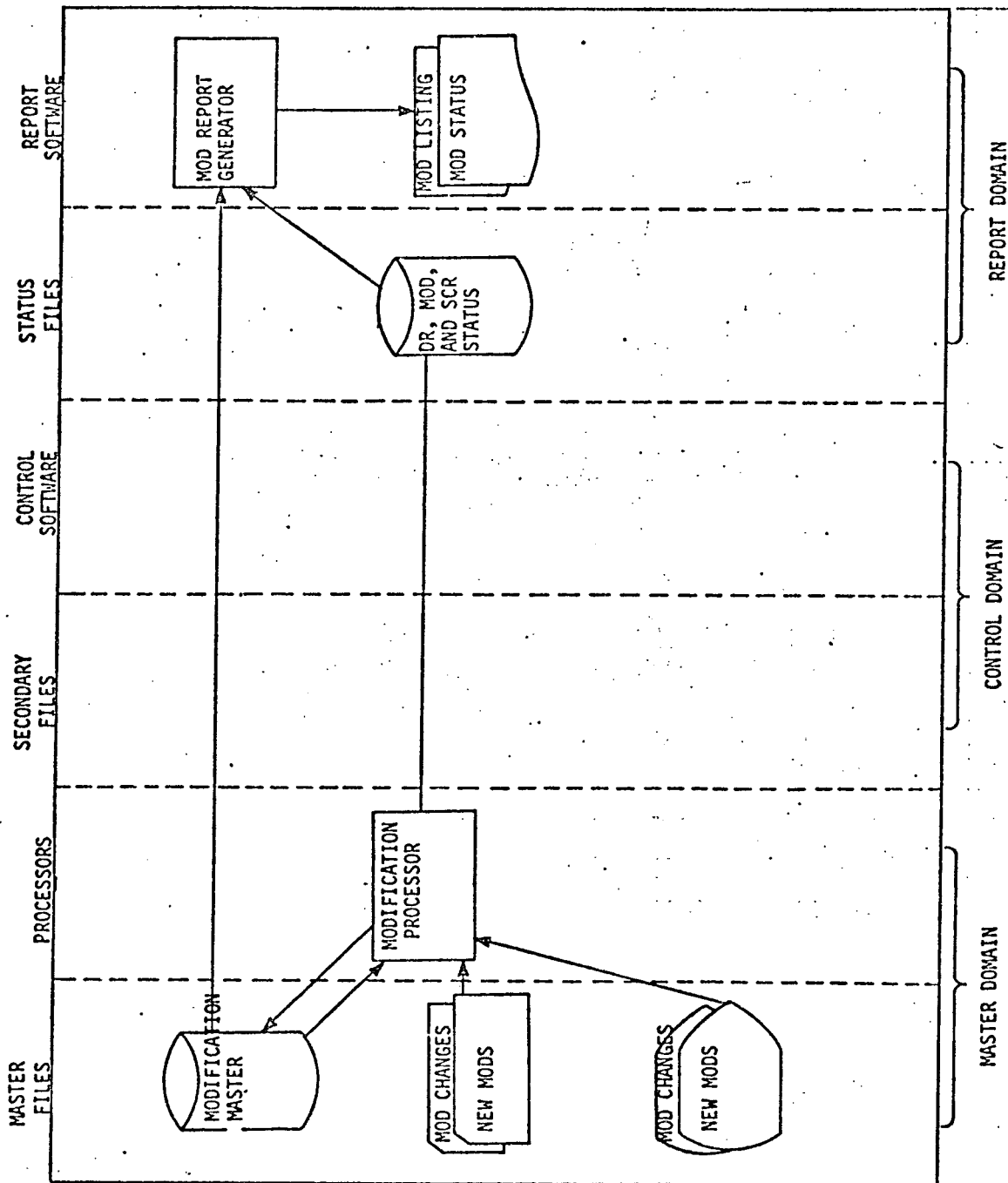
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3.4.2.9.3.2 Report Software

The reports generated utilize data contained in the Modification Master file. These reports may concern the entire file or any specific mod. Two reports are generated: the mod listing and the mod status. The status for any specified mod could be requested from any CRT and displayed in real-time. Contained in the mod listing will be all associated SCR numbers.

3.4.2.9 Modifications



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3.4.2.10 Software Change Requests

This system will provide the means of monitoring software change requests (SCR's).

3.4.2.10.1 Master Domain

3.4.2.10.1.1 Master Files

The SCR Master file will contain the SCR update. Contained in this file will be additional information such as the individual writing the SCR, date, and DR or mod with which the SCR is associated.

3.4.2.10.1.2 Processors

The SCR will be put into the system via CRT or cards. The SCR processor will then assign a number to the SCR. Any SCR on the SCR master that is in test status may be modified through the SCR processor. The SCR status will be maintained with input from the DR, Mod, and SCR Status File.

3.4.2.10.2 Control Domain

3.4.2.10.2.1 Secondary File

None

3.4.2.10.2.2 Control Software

None

3.4.2.10.3 Report Domain

3.4.2.10.3.1 Status Files

The information contained in the DR, Mod and SCR Status File (See Section 3.4.2.1.1.1) is incorporated into the SCR master file for use in generating the SCR status report.

3.4.2.10.3.2 Report Software

The reports generated utilize the data contained in the SCR master file. The reports may be concerned with all SCR's, SCR's associated with a particular DR or mod, or individual SCR's. Two reports are generated: SCR

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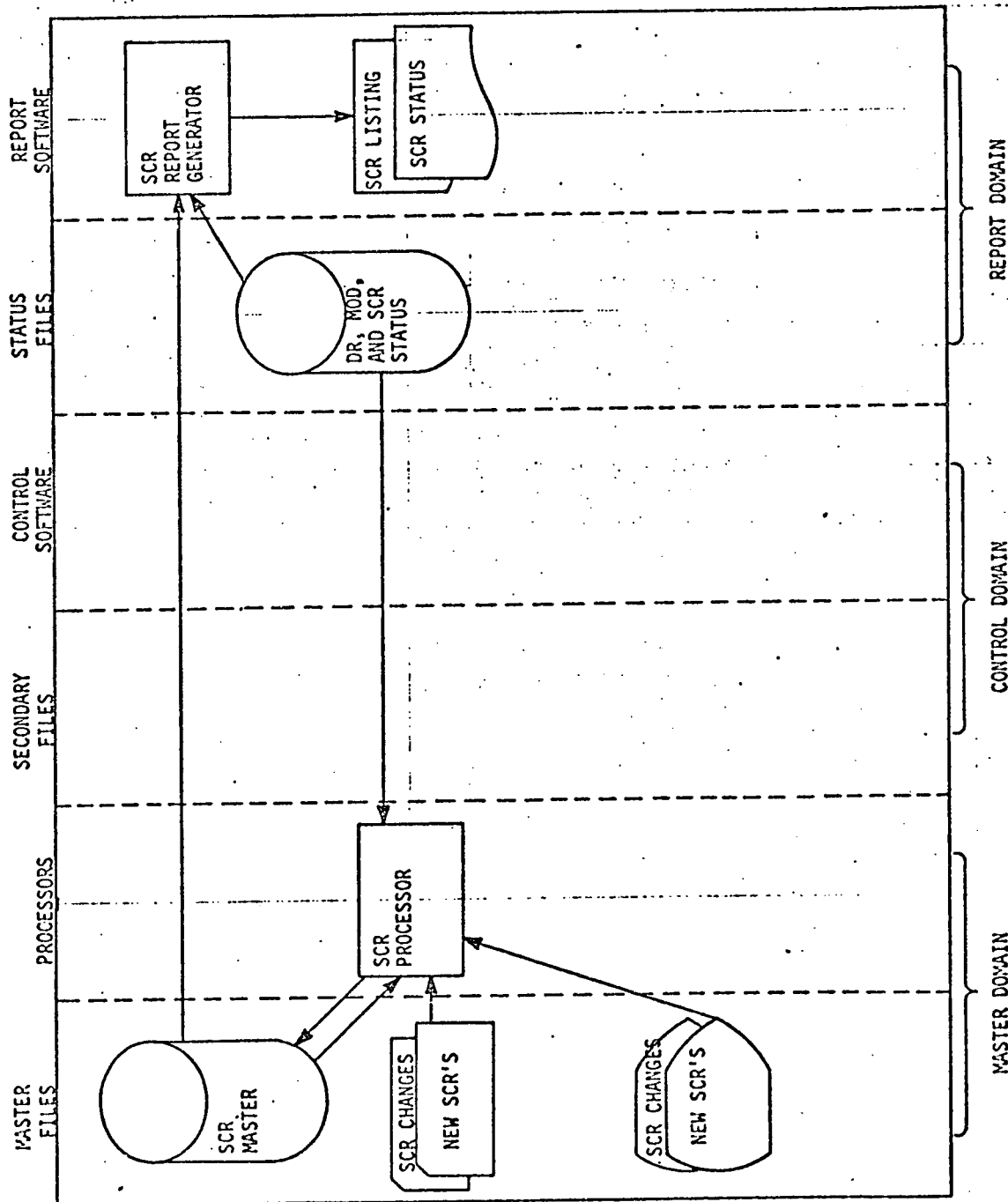
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listings and SCR status reports. The SCR listing will serve as documentation for DR's and mods that have been incorporated into the simulator system.

3.4.2.10 Software Change Requests



3.4.2.11 Simulator Hardware Documentation

This system will provide a means of monitoring the status of Hardware Change Notices (HCN's) and changes to the wire list.

3.4.2.11.1 Master Domain

3.4.2.11.1.1 Master Files

The two master files associated with simulator hardware documentation are the HCN Master and the Wire List Master. The HCN Master will contain all the HCN's that are in the process of being implemented with the current status. The Wire List Master will contain the current wire lists.

3.4.2.11.1.2 Processors

The HCN Processor maintains the HCN Master file by adding HCN's, changing HCN's or changing the status of HCN's. HCN's may be added or changed via CRT or cards. The status change may be entered via CRT or cards or if the HCN is associated with a software mod or DR, the status change can be from the DR, Mod, and SCR Status file. When an HCN status is changed to acceptance, the wire list changes associated with it are written to a secondary file to be input to the Patching and Schematics Processor. The Patching and Schematics Processor utilizes this file to update the Wire List Master file.

3.4.2.11.2 Control Domain

3.4.2.11.2.1 Secondary Files

A secondary file of wire lists changes is generated by the HCN Processor and used by the Patching and Schematics Processor to update the Wire List Master file.

3.4.2.11.2.2 Control Software

None

3.4.2.11.3 Report Domain

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3.4.2.11.3.1 Status Files

The information contained in the DR, Mod and SCR Status File (See Section 3.4.2.1.1.1) is used to update the HCN status in the HCN Master file for those HCN's associated with software mods and DR's.

3.4.2.11.3.2 Report Software

The HCN Report Generator utilizes information from the HCN Master file to generate HCN listings and an HCN status report. The Wire List Report Generator utilizes the Wire List Master file to generate the wire list report. Both of these report generators may utilize the entire file associated with it or any specified portion of the file. Additional information for the Wire List Report is obtained from the CDF and the Alpha file.

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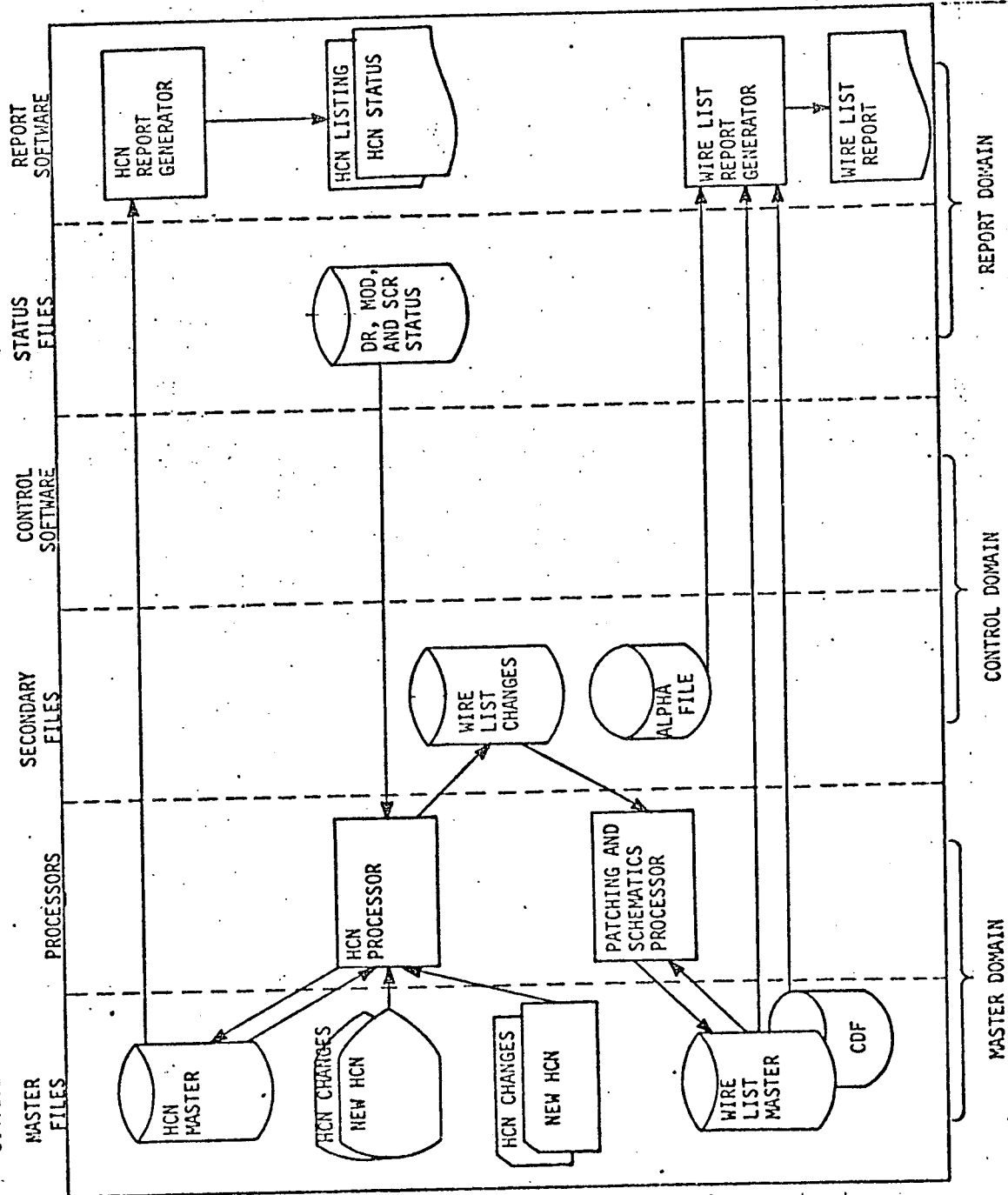
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3.4.2.11 Hardware Simulation Documentation



3.5 COMPUTER COMPLEX CONCEPTUAL DESIGN

3.5.1 Task Definition

The first step in the process of determining efficient candidate computer complex configurations is the definition of the tasks that must be performed. The host computer system must support a simulation task which is comprised of two simulation packages that must function simultaneously and independent of each other. The other task that the system must support is a time sharing task which is comprised of batch processing and interactive programming.

3.5.1.1 Simulation Task

The Shuttle Mission Simulator (SMS) will be divided into two training stations. One of the training stations will be on a six degree of freedom motion base (MCBS), while the other training station will be on a fixed base (FBCS). The host computer system must provide the capability for simultaneous, independent training activities in both training stations. Figure 3.5.1.1-1 defines the configuration of SMS in a functional manner. The following paragraphs define in more detail the hardware and software requirements of the simulation task.

3.5.1.1.1 Computational Requirements

Table 3.5.1.1.1-1 identifies in detail the computer loading that is required for the MBCS and FBCS. In order to maintain uniformity for all candidate computers, an instruction is equivalent in size to one computer word.

A summary of the computational requirements for the SMS is given below:

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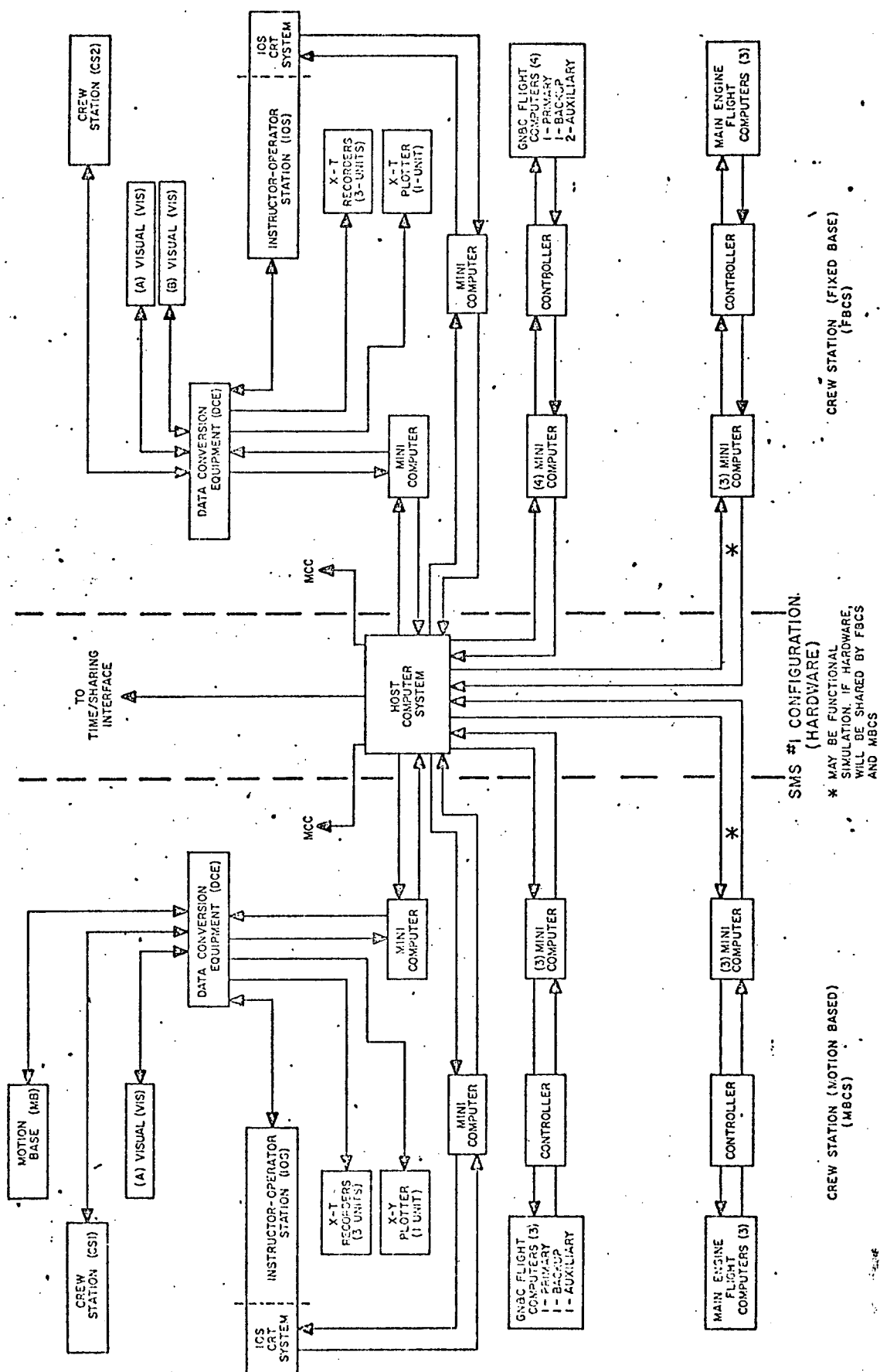


FIGURE 3.5.1.1-1

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SMS COMPUTER LOADINGS		Table 3.5.1.1.1-1															
SYSTEM		MOTION BASE STATION														MARCH 23, 1973	
SUBSYSTEM																	
EQUATIONS OF MOTION																	
TARGET VEH. ROT. EOM																	
TARGET VEH. TRN. LO																	
TARGET VEH. TRN. HI																	
SHUTTLE ROT. EOM																	
SHUTTLE TRN. EOM LO																	
SHUTTLE TRN. EOM HI																	
SYSTEM TOTAL																	
AERO																	
TARGET VEH. AERO																	
SHUTTLE VEH. AERO																	
SYSTEM TOTAL																	
WES																	
TARGET MASS PROP.																	
SHUTTLE MASS PROP.																	
SYSTEM TOTAL																	
EPHEMERIS																	
ALL																	
SYSTEM TOTAL																	
PAYLOAD																	
SYSTEM TOTAL																	
G.N. & C.																	
IMU																	
STAR TRACKER																	
HORIZON SENSOR																	
AIR DATA COMP.																	
RATE SENSORS																	
B.M. ACCELEROMETERS																	
MPS TVC																	
OMS TVC																	
SRM TVC																	
AEROSURF. CONT.																	
TARGET VEH. GUID.																	
SYSTEM TOTAL																	
CAUTION & WARNING																	
ALL																	
SYSTEM TOTAL																	
EPS																	
ALL																	
SYSTEM TOTAL																	
APU																	
ALL																	
SYSTEM TOTAL																	
HYDRAULIC POWER																	
ALL																	
SYSTEM TOTAL																	
SSME																	
INT. PKG. ESIG. CONT																	
COWND BUFF HAND																	
INTRR BUFF HANDLER																	
FUNCTIONAL 2 PER																	
FUNCTIONAL 5 PER																	
FUNCTIONAL 20 PER																	
SYSTEM TOTAL																	

SUBSYSTEM	NUMBER OF EQUATIONS	NUM. OF INST.'S	DATA BASE	PROG. BUFFER	ITER RATE	INSTRUCTIONS PER SECOND BY MISSION PHASE PRELAUNCH ORBIT BOOST ENTRY APP/LAND FERRY
RCS	195	1181	177	0	5	5905 5905 5905
SLOW RATE	20	121	18	0	10	6050 6050 C
INT. RATE	70	424	63	0	20	84800 84800 O
FAST RATE		1726	258	0		96755 96755 O
SYSTEM TOTAL						
OMS	200	1211	181	0	5	9082 9082 9082 C
SLOW RATE	120	727	109	0	20	21810 21810 O
FAST RATE		1938	290	0		30892 30892 O
SYSTEM TOTAL						
ABE	1700	10301	1545	0	5	0 0 0 206020
ALL		10301	1545	0		0 0 0 206020
SYSTEM TOTAL						
SRM	200	1211	781	600	20	0 0 0 0
ALL		1211	781	0		48440 48440 0 0
SYSTEM TOTAL						
ETSL	30	151	22	0	10	1510 1510 0 0
ALL		151	22	0		1510 1510 0 0
SYSTEM TOTAL						
CRYOGENICS	100	706	105	0	2	2824 2824 2824 2824
ALL		706	105	0		2824 2824 2824 2824
SYSTEM TOTAL						
VOICE COMM	125	631	94	0	2	1262 1262 1262 1262
ALL		631	94	0		1262 1262 1262 1262
SYSTEM TOTAL						
TV LOGIC	125	631	94	0	2	1262 1262 1262 1262
ALL		631	94	0		1262 1262 1262 1262
SYSTEM TOTAL						
DCS	500	2000	299	0	2	4000 4000 4000 4000
SLOW LOOP	600	2400	359	0	10	2399 2399 2399 2399
FAST LOP		4400	658	0		6399 6399 6399 6399
SYSTEM TOTAL						
UHF	125	631	94	0	2	2524 2524 2524 2524
ALL		631	94	0		2524 2524 2524 2524
SYSTEM TOTAL						
VHF RANGING	125	631	94	0	2	2524 2524 2524 2524
ALL		631	94	0		2524 2524 2524 2524
SYSTEM TOTAL						
ANTENNA PATTERNS	125	631	2094	2000	2	1262 1262 1262 1262
ALL		631	2094	0		1262 1262 1262 1262
SYSTEM TOTAL						
S-BAND	125	631	94	0	2	2524 2524 2524 2524
ALL		631	94	0		2524 2524 2524 2524
SYSTEM TOTAL						
T/M	10	60	3508	3500	2	60000 60000 60000 60000
LOGIC	40	240	6035	6000	2	240000 240000 240000 240000
FORMAT		300	9543	0		300000 300000 300000 300000
SYSTEM TOTAL						
ECS	1346	9516	1427	0	1	17128 17128 17128 17128
1 PER SECOND	1247	8816	1322	0	2	24684 24684 24684 24684
2 PER SECOND	670	4736	710	0	5	23680 23680 23680 23680
5 PER SECOND		23068	3459	0		65492 65492 65492 65492
SYSTEM TOTAL						

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SYSTEM	SUBSYSTEM	NUMBER OF EQUATIONS	NUM. OF INST.'S	DATA BASE	PROG. BUFFER	ITER RATE	INSTRUCTIONS PER SECOND	ORBIT	MISSION PHASE	ENTRY	APP/LAND	FERRY	
MECHANICAL													
	DRAG CHUTE	5	25	3	0	5	0	0	0	0	125	125	
	LANDING GEAR	75	378	56	0	10	0	0	0	0	5670	5670	
	SYSTEM TOTAL		403	59	0		0	0	0	0	5795	5795	
NAV. AIDS													
	ILS/MLS	200	1211	181	0	10	3027	3027	3027	3027	24220	24220	
	TACAN	295	1787	268	0	10	53610	53610	53610	53610	53610	53610	
	RADAR ALTIMETER	120	727	15109	15000	10	2180	2180	2180	2180	21810	21810	
	ATC TRANSPONDER	10	60	8	0	1	60	60	60	60	60	60	
	SYSTEM TOTAL		3785	15566	0		58877	58877	58877	58877	99700	99700	
VISUAL													
	20 PER	1750*	1767	265	0	20	81281	81281	81281	81281	81281	81281	
	10 PER	750*	757	113	0	10	9840	9840	9840	9840	9840	9840	
	5 PER	500*	504	75	0	5	3527	3527	3527	3527	3527	3527	
	1 PER	2250*	2272	340	0	1	3862	3862	3862	3862	3862	3862	
	SYSTEM TOTAL		5300	793	0		98510	98510	98510	98510	98510	98510	
MOTION													
	10 PER	30*	30	4	0	10	300	300	300	300	269	269	
	5 PER	100*	100	14	0	5	500	500	500	500	500	500	
	SYSTEM TOTAL		130	18			800	800	800	800	769	769	
SMS GSSC													
	ALL	1500*	1500	224	0	20	30000	30000	30000	30000	30000	30000	
	SYSTEM TOTAL		1500	224	0		30000	30000	30000	30000	30000	30000	
EXECUTIVE													
	ALL	500*	500	74	0	20	10000	10000	10000	10000	10000	10000	
	SYSTEM TOTAL		500	74	0		10000	10000	10000	10000	10000	10000	
CRT PROCESSOR													
	ALL	5000*	5000	37749	37000	1	50000	50000	50000	50000	50000	50000	
	SYSTEM TOTAL		5000	37749	37000		50000	50000	50000	50000	50000	50000	
RTIO													
	ALL	5000*	5000	749	0	15	75000	75000	75000	75000	75000	75000	
	SYSTEM TOTAL		5000	749	0		75000	75000	75000	75000	75000	75000	
MASTER CONTROL													
	SLOW LCOP	500*	500	74	0	20	10000	10000	10000	10000	10000	10000	
	FAST LCOP	4000*	4000	599	0	1	4000	4000	4000	4000	4000	4000	
	SYSTEM TOTAL		4500	673	0		14000	14000	14000	14000	14000	14000	
MASTER TIMING													
	ALL	1000*	1000	149	0	20	20000	20000	20000	20000	20000	20000	
	SYSTEM TOTAL		1000	149	0		20000	20000	20000	20000	20000	20000	
MATH LIBRARY													
	ALL	2500*	2500	0	0	0	0	0	0	0	0	0	
	SYSTEM TOTAL		2500	0	0		0	0	0	0	0	0	
UTILITY													
	ALL	2000*	2000	0	0	0	0	0	0	0	0	0	
	SYSTEM TOTAL		2000	0	0		0	0	0	0	0	0	
TOTALS			135680	100886			2228600	2805495	2278886	2431602	2192954	1827992	

* REPRESENTS AN INPUT NUMBER OF INSTRUCTIONS WHERE THE NUMBER OF EQUATIONS WAS UNAVAILABLE
 + PROGRAM ACTUALLY EXECUTED AT A RATE OF ONCE EVERY EIGHT SECONDS

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SMS COMPUTER LOADINGS		FIXED BASE STATION													MARCH 23, 1973	
SYSTEM	SUBSYSTEM	NUMBER OF EQUATIONS	NUM. OF INST.'S	DATA BASE	PROG. BUFFER	ITER RATE	INSTRUCTIONS PER SECOND	PRELAUNCH	BOOST	ORBIT ENTRY	PHASE APP/LAND	FERRY				
EQUATIONS OF MOTION																
	TARGET VEH. ROT. EOM	130	787	118	0	10	0	94440	90505	90505	47220	0				
	TARGET VEH. TRN. LO	95	575	86	0	0+	0	1775	2130	2130	0	0				
	TARGET VEH. TRN. HI	215	1302	195	0	10	0	130200	97650	104160	48825	0				
	SHUTTLE ROT. EOM	105	636	95	0	20	50880	50880	50880	50880	50880	50880				
	SHUTTLE TRN. EOM LO	90	545	81	0	0+	0	0	340	0	0	0				
	SHUTTLE TRN. EOM HI	195	1181	177	0	20	21257	28343	24800	30705	16533	16533				
	SYSTEM TOTAL		5026	752			72137	305638	266305	278380	163458	67413				
AERO																
	TARGET VEH. AERO	130	787	7118	7000	10	0	19675	7870	19675	15740	0				
	SHUTTLE VEH. AERO	260	1575	9236	9000	20	0	14174	7875	18859	18899	18899				
	SYSTEM TOTAL		2362	16354			0	33849	15745	38574	34639	18899				
WCB																
	TARGET MASS PROP.	15	90	13	0	2	0	2700	2070	2070	1080	0				
	SHUTTLE MASS PROP.	40	242	36	0	10	29040	29040	18150	29040	29040	29040				
	SYSTEM TOTAL		332	49			29040	31740	20220	31110	30120	29040				
EPHEMERIS																
	ALL	40	242	36	0	10	483	1451	1451	1451	1451	483				
	SYSTEM TOTAL		242	36			483	1451	1451	1451	1451	483				
PAYLOAD																
	ILLUMINATION	70	424	63	0	5	2120	2120	2120	2120	2120	2120				
	DOORS	25	151	22	0	5	755	755	755	755	755	755				
	MANIPULATORS	130	787	118	0	10	0	62960	0	0	0	0				
	ATTACHMENT	2300	13937	2090	0	10	2787	1393700	2787	2787	2787	2787				
	SYSTEM TOTAL	140	16147	2420	0	10	5662	5662	1501935	5662	5662	5662				
G.N. & C.																
	IMU	375	2272	340	0	20	249920	249920	249920	249920	249920	249920				
	STAR TRACKER	240	1454	218	0	20	159940	159940	159940	159940	0	0				
	HORIZON SENSOR	150	908	136	0	2	0	5448	5448	5448	0	0				
	AIR DATA COMP.	100	605	90	0	20	42350	42350	3629	42350	42350	42350				
	RATE SENSORS	50	302	45	0	20	27180	27180	27180	27180	27180	27180				
	B.M. ACCELEROMETERS	40	242	36	0	20	19360	19360	19360	19360	19360	19360				
	MPS TVC	375	2272	340	0	20	204480	204480	0	0	0	0				
	OMS TVC	300	1817	272	0	20	10901	90850	90850	90850	90850	90850				
	SRM TVC	375	2272	340	0	20	136320	136320	0	0	0	0				
	AEROSURF. CONT.	450	2726	408	0	20	163560	163560	81780	163560	163560	163560				
	TARGET VEH. GUID.	40	242	36	0	10	12100	12100	12100	0	0	0				
	SYSTEM TOTAL		15112	2261			854071	1111508	650207	758608	593220	502370				
CAUTION & WARNING																
	ALL	600	4241	636	0	2	33928	33928	33928	33928	33928	33928				
	SYSTEM TOTAL		4241	636			33928	33928	33928	33928	33928	33928				
EPS																
	ALL	2510	12675	1901	0	5	126750	126750	126750	126750	126750	126750				
	SYSTEM TOTAL		12675	1901			126750	126750	126750	126750	126750	126750				
APU																
	ALL	500	2524	378	0	5	50480	50480	50480	50480	50480	50480				
	SYSTEM TOTAL		2524	378			50480	50480	50480	50480	50480	50480				

SYSTEM SUBSYSTEM	NUMBER OF EQUATIONS	NUM. OF INST.'S	DATA BASE	PROG. BUFFER	ITER RATE	INSTRUCTIONS PER SECOND BY MISSION PHASE			APP/LAND	FERRY
						PRELAUNCH	BOOST	CRBIT ENTRY		
S-BAND	125	631	94	0	2	2524	2524	2524	2524	2524
ALL		631	94							
SYSTEM TOTAL										
T/H										
LOGIC	10	60	3508	3500	2	60000	60000	60000	60000	60000
FORMAT	40	240	6035	6000	2	240000	240000	240000	240000	240000
SYSTEM TOTAL		300	9543			300000	300000	300000	300000	300000
ECS										
1 PER SECOND	1346	9516	1427	0	1	17128	17128	17128	17128	17128
2 PER SECOND	1247	8816	1322	0	2	24684	24684	24684	24684	24684
5 PER SECOND	670	4736	710	0	5	23680	23680	23680	23680	23680
SYSTEM TOTAL		23068	3459			65492	65492	65492	65492	65492
MECHANICAL										
DRAW CHUTE	5	25	3	0	5	0	0	0	125	125
LANDING GEAR	75	378	56	0	10	0	0	0	5670	5670
SYSTEM TOTAL		403	59			0	0	0	5795	5795
NAV. AIDS										
ILS/MLS	200	1211	181	0	10	3027	3027	3027	24220	24220
TACAN	295	1787	268	0	10	53610	53610	53610	53610	53610
RAIDAR ALTIMETER	120	727	15109	15000	10	2180	2180	2180	21810	21810
ATC TRANSPONDER	10	60	8	0	1	60	60	60	60	60
SYSTEM TOTAL		3785	15366			58877	58877	58877	99700	99700
VISUAL										
20 PER	3500*	3534	530	0	20	162563	162563	162563	162563	162563
10 PER	1500*	1514	227	0	10	19681	19681	19681	19681	19681
5 PER	1000*	1009	151	0	5	7062	7062	7062	7062	7062
1 PER	4500*	4544	681	0	1	7724	7724	7724	7724	7724
SYSTEM TOTAL		10601	1589			197030	197030	197030	197030	197030
MOTION										
SYSTEM TOTAL		0	0			0	0	0	0	0
SMS GSSC										
ALL	1500*	1500	224	0	20	30000	30000	30000	30000	30000
SYSTEM TOTAL		1500	224			30000	30000	30000	30000	30000
EXECUTIVE										
ALL	500*	500	74	0	20	10000	10000	10000	10000	10000
SYSTEM TOTAL		500	74			10000	10000	10000	10000	10000
CRT PROCESSOR										
SYSTEM TOTAL	5000*	5000	46749	46000	1	63999	63999	63999	63999	63999
CRT PROCESSOR FIXED										
SYSTEM TOTAL	5000*	5000	46749			63999	63999	63999	63999	63999
RTIO										
ALL	5000*	5000	749	0	15	75000	75000	75000	75000	75000
SYSTEM TOTAL		5000	749			75000	75000	75000	75000	75000
MASTER CONTROL										
SLOW LOOP	500*	500	74	0	20	10000	10000	10000	10000	10000
FAST LOOP	4000*	4000	599	0	1	4000	4000	4000	4000	4000
SYSTEM TOTAL		4500	673			14000	14000	14000	14000	14000
MASTER TIMING										
ALL	1000*	1000	149	0	20	20000	20000	20000	20000	20000
SYSTEM TOTAL		1000	149			20000	20000	20000	20000	20000

SYSTEM SUBSYSTEM	NUMBER OF EQUATIONS	NUM. OF INST.'S	DATA BASE	PROG. BUFFER	ITER RATE	INSTRUCTIONS PRELAUNCH	PER SECOND BOOST	BY MISSION ORBIT	PHASE ENTRY	APP/LAND	FERRY
MATH LIBRARY											
ALL	2500*	2500	0	0	0	0	0	0	0	0	0
SYSTEM TOTAL		2500	0			0	0	0	0	0	0
UTILITY											
ALL	2000*	2000	0	0	0	0	0	0	0	0	0
SYSTEM TOTAL		2000	0			0	0	0	0	0	0
TOTALS		156998	113084			2345981	2922876	3692571	2548983	2310366	1945404

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TRAINING
STATIONEXECUTABLE
INSTRUCTIONSDATA
BASEMIP

MBCS

136K

101K

2.9

FBCS

157K

114K

3.9

TOTAL:

293K

215K

6.8

3.5.1.1.2 Input/Output Requirements

The input/output requirements for the SMS can be categorized into three major areas for each training situation:

• DATA CONVERSION EQUIPMENT (DCE)TRAINING
STATIONDEVICECHANNELSSERVICE
RATE

MBCS

Digital Input

2268

20/sec

Digital Output

2261

20/sec

Digital/Analog

791

20/sec

Analog/Digital

182

20/sec

TOTAL:

5502*

FBCS

Digital Input

2851

20/sec

Digital Output

4295

20/sec

Digital/Analog

493

20/sec

Analog/Digital

48

20/sec

TOTAL:

7687*

Data rate for host computer to/from DCE Mini:

MBCS 110,040 words/sec

FBCS 153,740 words/sec

* One computer word/DCE device channel

① IOS CRT SYSTEMS

Data rate for host computer to Mini:

MBCS 35,000 words/sec

FBCS 45,000 words/sec

① FLIGHT COMPUTER SIMULATION

Both the MBCS and FBCS must support the following worst case flight computer interfaces:

	<u>MAIN ENGINE</u>	<u>AVIONICS</u>
Transfer rate	1 MW/sec	1 MW/sec
Word size	16 bits	32 bits
Data rate:		
Input	25/sec	25/sec
Output	25/sec	25/sec
Data block	200 words	400 words
Number of computers	3	4
Transfer rate (Host Computer)	30,000 wd/sec	80,000 wd/sec

3.5.1.2 Time-Sharing Task

The host computer system must provide the capability to support local/remote batch processing and interactive programming in a multiprogramming or multiprocessing mode. Figure 3.5.1.2-1 defines the functional time-sharing and on-line peripheral requirements that the host computer system must support.

3.5.1.2.1 Facilities① Batch Stations

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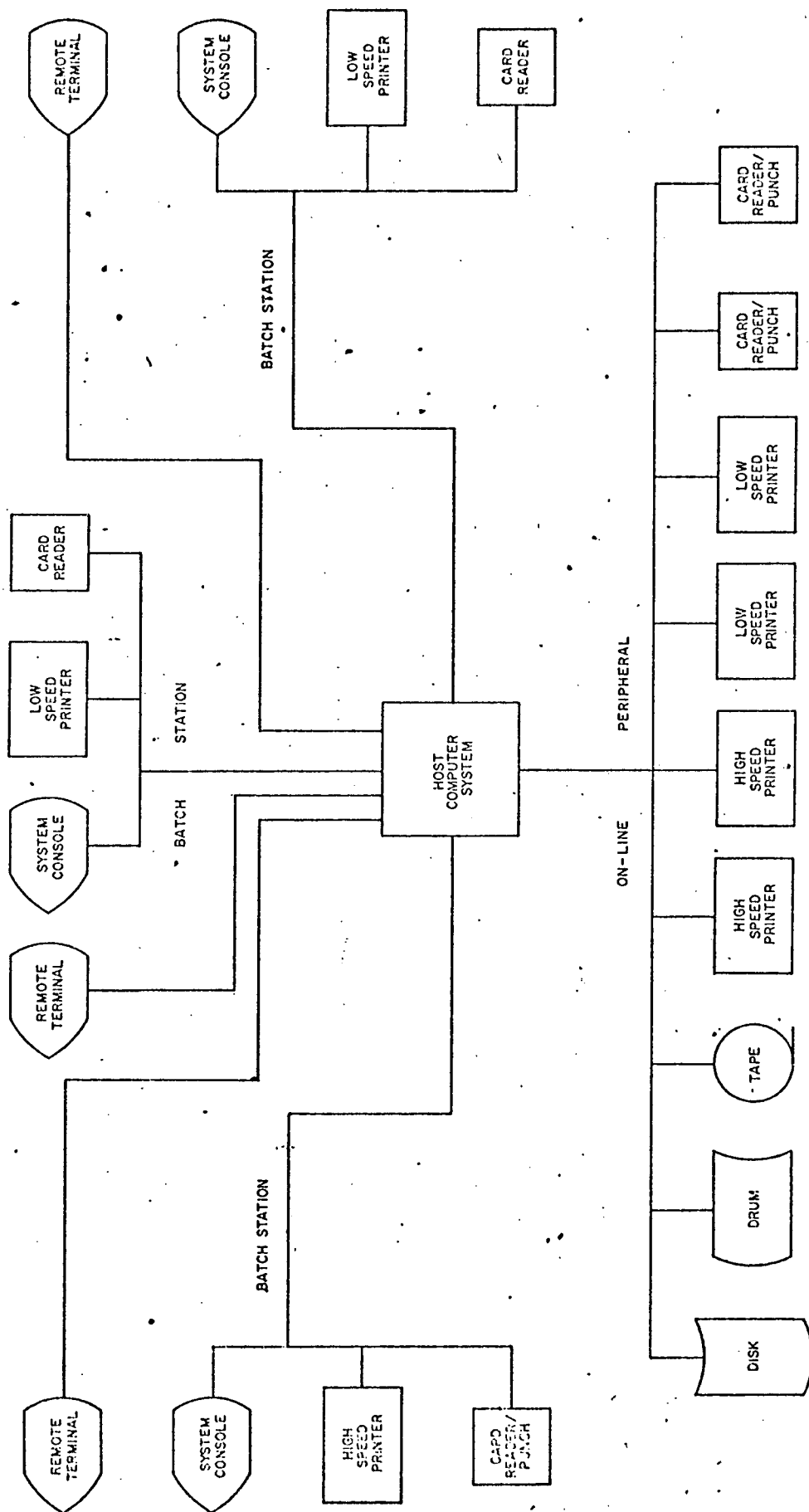
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TIME SHARING CONFIGURATION

FIGURE 3.5.1.2-1

- Simulator Contractor (Off-Site)

- Line Printer

- Card Reader/Punch

- Operator Console

- Building 4 (On-Site)

- Line Printer

- Card Reader

- Operator Console

- Building 5 (On-Site)

- Line Printer

- Card Reader

- Operator Console

- Interactive Terminals

A total of 15 terminals will be required. Five terminals will be located at each of the buildings previously specified. The terminals will not necessarily be located in the immediate area of the Batch Station.

3.5.1.2.2 Capabilities

- Throughput

- Local/remote batch: 600 jobs/24 hours

- Interactive terminals: 60% utilization

- Job Types (typical)

- Compiles (FORTRAN - 75%, COBOL - 15%)*

- Assemblies (10%)*

- Compile, Load, Go

- File Management

*500 to 1,000 statements per compilation or assembly.

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- Data Reduction
- Data Management System
- Load Module (one or more programs) Creation and Checkout
- Language Processors (minimum)
 - Conversational FORTRAN
 - Conversational COBOL
 - Conversational Assembler
 - Data Management System (CODASYL Standard)
 - Conversational Debug Package
 - User Generated
- Job Initiation
 - Local/remote batch station
 - Interactive Terminal
- MIP Requirements - 1.0

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3.5.2 Computer Complex Requirements

The requirements specified in the following paragraphs will provide a computer complex configuration which may be used in an efficient and flexible manner.

3.5.2.1 Host Computer System

• <u>MIP Rate-</u>	6.8	(Simulation)
	1.0	(Time-Sharing)
	.5	(Operating System)
Subtotal	8.3	(Allocated)
	3.4	(Spare)
Total	~ 12.0	(Capacity)

• Word Size - 32 Bit (minimum)

<u>Floating Point</u>	<u>Sign</u>	<u>Exponent</u>	<u>Fraction</u>
Single Precision	1 Bit	7 Bits	24
Double Precision	1 Bit	7 Bits	48
<u>Fixed Point</u>			
Single Precision	Sign Bit + 31 Bits		
Double Precision	Sign Bit + 59 Bits		

• Registers - 16 (general)• Addressable Core Storage (minimum)

	<u>Instructions</u>	<u>Data Base</u>
MBCS	136K	101K
FBCS	157K	114K
TOTAL	293K	215K

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• Instruction Set Class

Load/Store

Binary

Decimal

Floating Point

Fixed Point

Logical

Test/Branch

Search/Compare

Shift

Index

Byte/String Manipulation

Supervisory

• Input/Output Channels

	<u>Number</u>	<u>Data Rate</u>
MBCS	8	200K Words/Sec
	1	100K Words/Sec
FBCS	8	200K Words/Sec
	1	100K Words/Sec

3.5.2.2 Time-Sharing Requirements

3.5.2.2.1 Batch Stations

• Simulator Contractor (Off-Site)

- 2 Line Printer: 600 LPM (minimum)/printer
- 1 Card Reader/Punch: 1200/250 CPM
- 1 Operator Console (CRT/Keyboard)

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- Building 4 (On-Site)

- 1 Line Printer: 600 LPM
- 1 Card Reader: 250 CPM
- 1 Operator Console (CRT/Keyboard)

- Building 5 (On-Site)

- 1 Line Printer: 600 LPM
- 1 Card Reader: 250 CPM
- 1 Operator Console (CRT/Keyboard)

- Baud Rates

- 9.6K Baud (minimum)
- 19.6K Baud (Satisfactory)
- 40.8K Baud (Simulator Contractor Only)

3.5.2.2.2 Interactive Terminals

- At each Site:

- 3 Alphanumeric

- 2 Alphanumeric/graphic (4 color)

- 1000 displayable characters/terminal

- Response rate - 1-3 secs

- 1 keyboard/terminal

- Light pen - optional

- 1 Hardcopy unit/terminal

- Baud rate - 2400 (minimum)

3.5.2.3 On-Line Peripheral Requirements

The on-line peripheral identified in the following paragraphs must be accessible by each CPU in the host computer system.

3.5.2.3.1 Rotating Mass Storage

• Disc

- Capacity: 1.7 billion characters
- Access Time: 30 M.S. (ave.)

• Drum

- Capacity: 22 million characters
- Access Time: 5 M.S. (ave.)

3.5.2.3.2 Magnetic Tape

• 6 - 800/1600 BPI 9 track

• 2 - 200/556/800 BPI 7 track

3.5.2.3.3 Line Printer

• 2 - 1200 LPM (minimum)

• 2 - 600 LPM (minimum)

3.5.2.3.4 Card Reader/Punch

• 2 - 1000 Read/250 Punch

3.5.2.3.5 Input/Output Channels

• Channels should be provided which will accommodate all peripheral equipment with minimum practical channel contention by the CPU(s) for all the peripheral.

3.5.2.3.6 Spare

• MIP:	<u>Minimum</u>	<u>Maximum</u>
	25%	50%

• 25% spare should be available for all other computer complex resources.

3.5.2.4 Operating System (OS)

3.5.2.4.1 Overhead

Based upon the requirements that have been identified in the previous sections, the maximum (worst case) overhead for the OS should be as follows:

Core - 75K words

Time - 0.5 MIP

3.5.2.4.2 General Capabilities

In general, the Operating System (OS) of the Host Computer must provide a hospitable environment for the proposed real-time simulation software and must contain certain intrinsic capabilities as follows:

- Capability for executing a mix of programs including batch, interactive, and real-time programs in multiprogramming or multiprocessing mode.
- Provide a user-accessible internal clock for synchronizing and timing events.
- Provide a capability for exploiting the inherent parallelism of real-world events reflected in simulation processes by permitting the initiation and termination (synchronization) of independent, asynchronous program execution sequences.
- Provide the ability to create and execute re-entrant code sequence.
- Provide a comprehensive interrupt structure with optional user handling of interrupts.
- Accommodate non-pollled communications (digital) input, both synchronous and asynchronous, at varying speeds and employing a variety of code formats and line disciplines.

It is recognized that these capabilities (as well as features described below) are made available by hardware or software (or both), depending on the architecture of the machine. Therefore, a functional description will be utilized unless a feature is clearly identifiable as hardware or software.

3.5.2.4.3 OS/Simulation Software Interface

The general relationship between the OS of the host machine and the required simulation software merits close examination as it can have a significant impact on the magnitude of the overall software programming task. Ideally, the host OS would provide all needed functions, thereby reducing the programming task to simulation software exclusively. In a worst case situation, there would be no host OS at all suitable as environment for the simulation software (in which case an OS would have to be developed in addition to the simulation software). The 'division of labor' between the OS and the simulation software must be carefully identified in order to correctly assess the relative merits of candidate OS's.

3.5.2.4.4 System Synchrony

In any large time-dependent system there must exist a means of achieving global synchrony of asynchronous events. This clearly involves several aspects:

- A user accessible real-time clock of suitable resolution.
- Ability of user programs to establish and receive time interrupts.
- Ability to initiate and synchronize asynchronous execution of multiple program modules.
- Ability to establish and alter execution priorities of program modules.

- Ability of the OS to establish and honor priorities for various execution modes (batch, interactive, and real-time).

- Ability to handle non-pollled input arriving at arbitrary intervals without data loss.

3.5.2.4.5 Global and Common Reference

The host software must provide a capability for the declaration and use of external (or global) references or names accessible to any referencing program module. In a like manner, it must provide the ability for program modules to share common data, e.g. 'named common' feature of FORTRAN. The realization of these features must be provided in the Link Edit or Collection phase discussed below.

3.5.2.4.6 Link Edit or Collection

The host software must allow the linking or collection of discrete software segments into executable modules. It must allow collection of object code resulting from different processors, e.g., FORTRAN and Assembler.

3.5.2.4.7 Interrupt Structure

The host machine must incorporate multi-level interrupts (internal, external, fault, etc.) as required in any multi-programmed environment. Additionally, the interrupt structure must include time-dependent (clocked) interrupts which can pass control from the OS to user programs. In general, the interrupt structure must allow optional user handling of interrupt contingencies and must also afford the user the option of not relinquishing control on the initiation of the I/O requests, if he so desires.

3.5.2.4.8 Program Residency/Non-Residency

In the event that the host machine cannot accommodate the entire simulation software as resident or simultaneously present, provision must be included for execution of non-resident elements through an overlay or paging mechanism (or the equivalent thereof). It is extremely important that this mechanism not compromise the basic time dependency and control outlined elsewhere on which the entire simulation program is postulated.

3.5.2.4.9 Language Processors

The host OS must contain language processors capable of processing user-supplied source language statements. In particular, a FORTRAN or higher level language processor must be supplied. For those needed computational functions not present in FORTRAN, an Assembler must also be provided and it must be possible to enter Assembler from FORTRAN and vice-versa. The FORTRAN processor must conform to current ANSI standards for the FORTRAN language. It must also be possible to link edit (collect) elements of FORTRAN and Assembler into a single program.

3.5.2.5.10 Libraries

The OS should provide at a minimum the following libraries:

- System Utility
- Mathematical
- Macro

3.5.2.5.11 Computer System Accounting

A statistics gathering system must be provided which will have the capability of accounting for the utilization of all computer system resources.

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3.5.3 Candidate Computer Configurations

3.5.3.1 Control Data Computer System

The CDC Computer System is comprised of one Cyber 70 Model 76 and one Cyber 70 Model 73. The Model 76 provides the capability to support the simulation task, while the Model 73 provides the capability to support the time sharing task. The two Cybers are interfaced together for the following reasons:

- The Model 73 will use the standard 6000 SCOPE 3.4 Operating System as a base and perform the following tasks in support of the SCOPE 2 Operating System in the Model 76. See Figure 3.5.3.1.-1.

- Unit Record Interface

It will be the interface between local unit record equipment such as card readers, line printers, punches, etc., and the Model 76 CPU.

- Communications Interface

It will be the interface between communication lines and the 7600 CPU. The communications interface will permit Remote Batch capabilities on the 7600 System.

- Model 73 Operator Station

The Model 73 can serve as either a normal station or the operator station having the ability to control the execution of all jobs in the Model 76.

- Permanent File Handling

The Model 76 will be provided ATTACH and CATALOG features of Model 73 permanent files.

3.5.3.1.1 Host Computer

- Model 76

- 15.0 MIP rate
- 60-bit internal word
- Binary computation in fixed point and floating point format.
- Nine independent functional units.
- 12-word instruction stack.
- Synchronous internal logic with 27.5 nanosecond clock period.
- Operating registers

Eight 60-bit operand registers (X registers)

Eight 18-bit address registers (A registers)

Eight 18-bit index registers (B registers)

- Precision

Fixed point range $\pm 2^{47} - 1$

Floating point range (magnitude) 10^{322} to 10^{-293}

Double precision capability

- Instruction set class

Arithmetic: Load/store.

Binary

Floating point

Fixed point

Logical

Test/Branch

Search/Compare

Shift

Index

Population count

Supervisory

- Small Core Memory

- 32,768 or 65,536 60-bit words of coincident current memory with five parity bits per 60-bit word.
- Organized into 16 or 32 independent banks (2,048 words per bank).
- 275 nanosecond read/write/cycle time.
- 27.5 nanosecond per word maximum transfer rate.

- Large Core Memory

- 256,000 or 512,000 60-bit words of linear select memory with four parity bits per 60-bit word.
- Organized into four or eight independent banks (64,000 words per bank).
- 1,760 nanosecond read/write/cycle time.
- Eight words read simultaneously each reference.
- 27.5 nanosecond per word maximum transfer rate (512,000 memory only).

- I/O Multiplexer

- Seven, eleven, or fifteen independent 12-bit channels.
- Each channel bi-directional.
- Fixed SCM buffer areas for each channel; 128 or 256 60-bit words.
- Normal channels and high speed channels.

	<u>Normal Channel</u>	<u>High Speed Channel</u>
Input:	60 clock periods/60-bit word	34 clock periods/60-bit word
Output:	72 clock periods/60-bit word	35 clock periods/60-bit word

● Peripheral Processor Unit Characteristics

- Computation Section

12-bit internal word

Binary computation in fixed-point

Synchronous internal logic with 27.5 nanosecond clock period

- Operating Registers

18-bit Arithmetic Register (A)

12-bit Program Address Register (P)

13-bit Memory Read Register (X)

12-bit Instruction Register (fd)

12-bit Working Register (Q)

- Core Memory

4,096 12-bit words of coincident current memory with a
parity bit for each 12-bit word (odd parity)

Organized into two independent banks (2,048 words per bank).

275 nanosecond read/write/cycle time

- Input/Output Section

Up to 15 independent channels (asynchronous)

Each channel bi-directional (12-bit)

● Maintenance Control Unit

- Used to dead start system

- Performs basic recovery

- Directs and monitors system maintenance

- Own card reader

- Own visual display

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3.5.3.1.2 Time Sharing

The time sharing system operated in the Cyber 70 Model 73 computer.

• Central Processor

- 60-bit word length.
- Computation in Floating Point and Fixed Point, Single and

Double Precision.

- Memory transfer rate of up to one word each 100 nsec.
- 60-bit instruction Buffer register.
- Memory protect
- 8 18-bit address registers
- 8 18-bit increment registers
- 8 60-bit operand registers

• Peripheral and Control Processor

- 12-bit word length
- Computation in Fixed Point arithmetic.
- Time-shared access to Central Memory.
- Internal memory of 4,096 12-bit words.

• Central Memory

- Capacities of 16,384, or 32,768, or 49,152, or 65,536 or 98,304, or 131,072 60-bit words.

- Independent bank construction, to allow separate overlapped access to each 4K bank.

- Transfer rate of up to one word each 100 nsec in phased operation.

• 711-1 CRT Display Terminal

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- 16 lines of 80 characters
- 10 X 8 inch viewing area
- Standard typewriter keyboard
- 64 alphanumeric and symbols plus control codes.
- RS232-C interface designed for synchronous data transmission

to 4800 BPS, half duplex.

- Cursor control:

Up

Down

Left

Right

Home

- Inverse Video
- 5 X 9 dot matrix using 525 line TV raster
- 60 HZ refresh rate
- Character size: .25 X .125 inch
- 732-10 Medium Speed Batch Terminal
 - 8K 8-bit bytes of 16-bit 1.1 μ s memory
 - 500 CPM reader
 - 600 LPM, 136 column printer
 - Operator keyboard
 - Designed to RS232C or CCITT V24 specifications
 - Speed range from 2000 to 9600 BPS
- 791-1 Communication Subsystem
 - Provides interface to 7077-1 or 7611-10 service station
 - Fan out logic for up to 48 communication adapters

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- Communication interface for up to 16 792 adapters
- 4096 16-bit core memory with 200 μ s cycle time
- 792-1 Communications Adapter
 - Performs input synchronization
 - Full duplex character assembly/disassembly
 - EIA RS232-C interface
 - Compatible with bell 201 and 203 data sets
 - May provide CCITT compatibility
 - Will operate at 2400, 4800 or 9600 BPS
- 7077-1 Communications Station
 - Controls up to three 791-1 controllers
 - Provides 8K words memory with 1.1 μ s cycle time
 - Requires one dedicated PPU

3.5.3.1.3 On-Line Peripheral

- 3528-3 Magnetic Tape Controller
 - Two channel connection
 - Controls up to 8 Model 657 or 659 (intermixed) tape units
 - Provides code conversion
 - 200, 556, and 800 BPI NRZI recording
 - 1600 BPI phase encoded
- 7611-11 Service Station
 - 32K bytes (6-bit byte) central memory
 - 80K bytes secondary memory
 - 142M bytes rotating mass storage
 - Dead start magnetic tape unit
 - Operating console
 - 8 I/O channels for MPX and unit record equipment

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- 405 Card Reader
 - 1200 CPM (80 column cards)
 - 4000 card hopper capacity
 - 4000 card stacker
 - 240 card secondary stacker
- 415 Card Punch
 - Punch 250 CPM
 - Programmable offset stacker
 - 1208 card hopper
 - 1500 card stacker
 - Read check after punch
- 512-1 Line Printer
 - Prints 1200 LMP (48 character set)
 - Skips 70 inches/sec at 6 lines/inch
 - Skips 60 inches/sec at 8 lines/inch
 - Prints 136 columns
- 657-4 Magnetic Tape Transport
 - 7 track
 - 30K and 120K 6-bit C/S
 - 200, 556, 800 BPI NRZI recording
 - Read/write 150 IPS
 - Forward/Reverse read
- 659-4 Magnetic Tape Transport
 - 9 track
 - 90 and 180K 8-bit C/S
 - 800 BPI NRZI recording

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- 1600 BPI phase encoded recording
- Read/write 150 IPS
- Forward/reverse read
- 844-2 Disk Storage Unit
 - Maximum capacity 869 million bits (unsectored format, 404 tracks)
 - 10-55 ms positioning time (30 ms average)
 - 618 million bits/sec transfer rate

3.5.3.1.4 Operating System (OS)

3.5.3.1.4.1 Overhead

• Cyber 73 (Scope 3.4)

- Core: 16K
- MIP: .0115

• Cyber 76 (Scope 2)

- Core: 65K
- MIP: .5

3.5.3.1.4.2 General Capabilities

- Provides the execution of a mixture of batch, interactive and real-time programs in a multiprogramming and multiprocessing mode.
- User is provided access to the system clock.
- The central processor initiates the I/O request. The PPU performs the requested I/O function while the central processor continues other work. At the end of the I/O function, the PPU will signal the central processor. The central processor can then determine whether or not to initialize any new procedures.

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- The interrupt sequences are normally re-entrant
- The interrupt structure is established by the hierarchy of I/O channels and system functions.
- Intelligent processors on remote interfaces can respond to various types of communications.

3.5.3.1.4.3 O/S Simulation Software Interface

There are structurally four parts to the central system, as shown in Figure 3.5.3.1.4-1. These are: the job supervisor, the interrupt handlers, the system executive, and the system interchange.

- System Interchange

The system interchange coordinates system operations by transferring control to the other parts of the system and assigning the CPU.

- Interrupt Handlers

The interrupt handlers service hardware/software interrupt functions. These functions include: the transfer I/O data between LCM buffers and the CPU channels via the hardware SCM buffers, the processing of clock interrupts, and the processing of software generated interrupts.

- System Executive

The system executive consists of overlays that perform system functions of resource allocations, scheduling, I/O request queue management, and some job management.

- Job Supervisor

The job supervisor performs functions specifically oriented to a single user job which include user level (or logical) I/O management, the reconciliation of logical and physical data structures, and file management. The job supervisor also performs tasks associated with the management

JOB ORIENTED FUNCTIONS

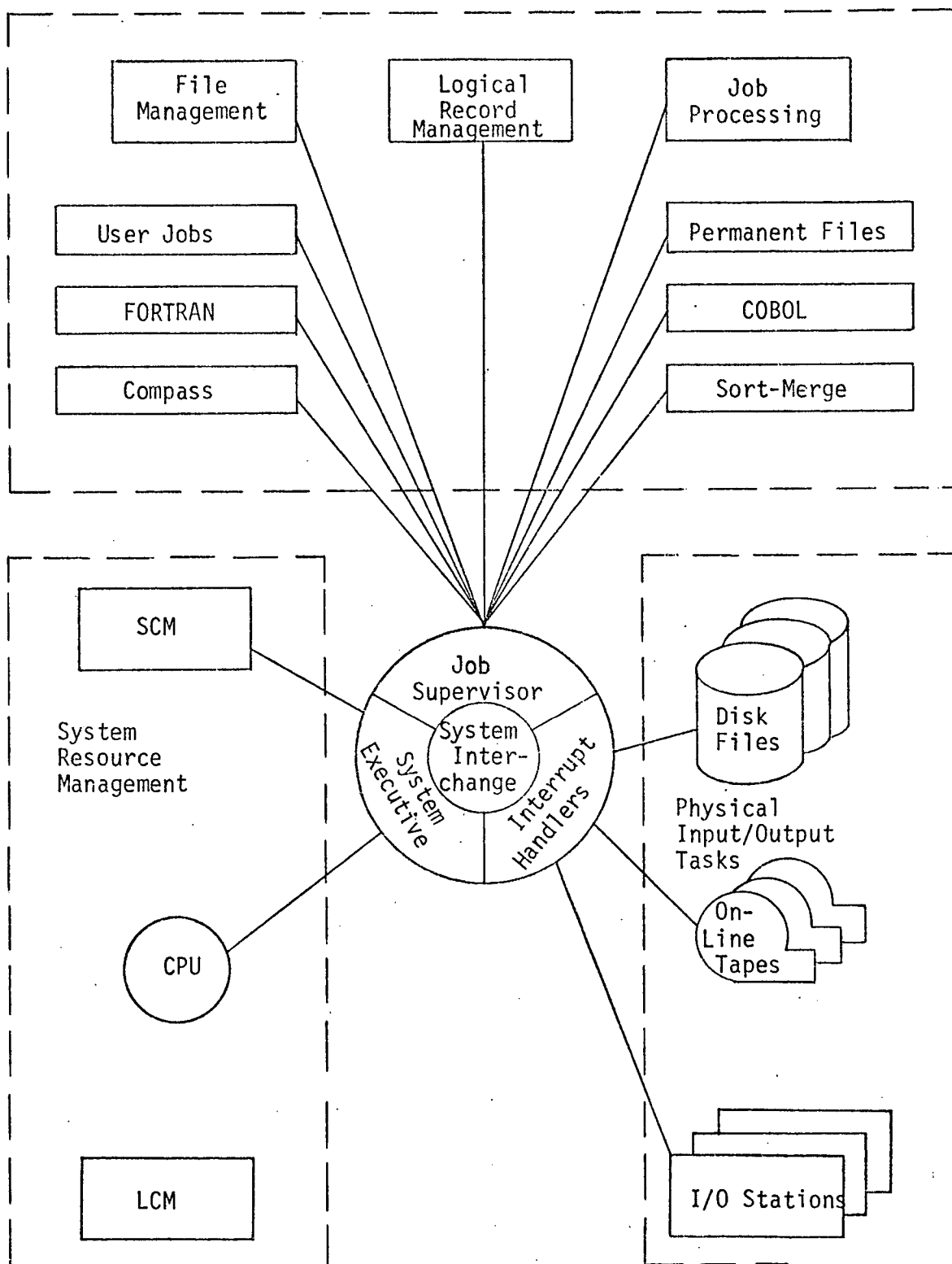


FIGURE 3.5.3.1.4-1

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of the user's job and user requested system services, such as TIME, DATE, etc.

There are three sub-divisions of the system executive. The three parts represent a priority sequence based on the time sensitivity of the classes of activities listed. The E3 level, or real-time interface has highest priority. The E2 level contains I/O functions. Because interrupt service is involved, the E2 level is given preference over the administrative functions of the system executive which are grouped at the E1 level.

One job at a time is connected to the system interchange and, as the job completes its fraction of CPU time assigned to it, the job scheduler attaches a different job supervisor and its related job to the system interchange for execution.

• Station Communication

Stations submit job files and data files to the SCOPE 2 operating system and receive user created output data files. Files are processed according to type: permanent files, magnetic tape, line printer, or card punch, etc.

The stations also provide the station console operator with communication features for monitoring the progress of and controlling jobs executing under SCOPE. SCOPE responds with messages or displays presented on the CRT of a station console. Displays, operator requests, and other operator messages are described in the operator's reference manual for the appropriate station.

• Job Processing

A job first enters the system when a job input file is created at a station. The station formats the file and transfers it to the central computer where the job is queued for execution. The system allocates resources to the job as needed for execution.

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The operating system interprets the control statements, calls the loader, calls compilers, and assembler, performs file manipulations and I/O, and provides permanent files as requested by the user.

SCOPE terminates the job by disposing of all files used or created by the job, by preparing the job's OUTPUT file for transmission to a station, and by de-allocating all resources used by the job.

Any file created by a job for transmission to a station, is queued in the central system and sent upon request by the station to be written on the appropriate peripheral device.

• Multi-Programming and Job Scheduling

SCOPE 2 provides multi-programming of jobs throughout the system. Multiple jobs reside in SCM, in LCM, and on system mass storage concurrently. The number of jobs residing in either SCM or LCM is a function of the job mix. The maximum number of jobs to be executed simultaneously is specified by installation parameter (maximum 4,096).

Access to the CPU and memory residence for all jobs in execution is reassessed on installation defined intervals, facilitating job progression on a priority basis.

The user may select job priority by job statement parameter or accept the default priority supplied by SCOPE. Once a job resides in the system, the external priority of the job does not change.

Job scheduling establishes job's residence progressively through three storage media: mass storage, LCM, and SCM. Jobs receive an aging increments while waiting in mass storage and LCM to ensure that no job is denied a chance to execute in SCM. Job field length requirements are evaluated against available memory to maximize use of large and small core memory.

• Memory Usage and Control

Each job while executing occupies contiguous address in SCM and/or LCM. Each job area is defined by reference addresses (RAS for SCM, RAL for LCM) and field lengths (FLS for SCM, FLL for LCM). If a program refers to an address outside its field length, hardware senses the error and range error processing occurs. The user may specify the action to take or simply allow job termination to occur. This memory protection hardware provides integrity in a multi-processing environment. Exit from a user program to the system (a hardware protected area) for processing of action requests is accomplished by execution of a monitor jump instruction.

Each job's field length contains an area (RAS+0 through RAS+77₈), reserved for communication with the system. Loader information, control statement images, and other job related information are maintained in this area. File related communication occurs via the file information table, which is declared and maintained in the user's field length.

An extension to the user field length is provided for every job to enable the execution of various system elements which service the user field length. In addition, this extension area contains exchange packages for the job, which contains the job's normal and abnormal exits, and memory field lengths and reference addresses. The system maintains the exchange packages for all executing jobs.

• Record Management

The record manager services user's input/output requests.

The record manager provides flexibility to the user in specifying I/O requirements, and performs required data movement automatically during execution. For instance, the user may either choose to be completely

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free of details of physically record formats (such as tape or disk formats), device assignment, and physical I/O, or specify them in detail by overriding default conditions.

3.5.3.1.4.3 System Synchrony

- Real time clock interval is 27.5 nsec.
- Interrupts can be set and controlled by the system.
- Jobs can be started by dependency criteria.
- System runs jobs on basis of type and priority.
- The PPU I/O system does not affect CPU operation until the software determines that it is necessary.

3.5.3.1.4.4 Global and Common Reference

Blank (Global) and labelled common features are available.

3.5.3.1.4.5 Link Edit or Collection

The SCOPE loader provides object time organization necessary for program execution. The loader translates programs, subprograms, or overlays in relocatable format into core image modules in absolute form for execution.

The loader also performs tasks for the user such as searching of user and system libraries to satisfy program directives for loading and linking memory references, and establishing entry addresses.

3.5.3.1.4.6 Interrupt Structure

Interrupt capabilities exist for I/O, arithmetic fault, memory range, and memory fault conditions.

3.5.3.1.4.7 Program Residency/Non-Residency

The capability for program overlay structure exists within the confines of the loader. In addition, LCM can serve as a zero access storage media for these overlays.

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3.5.3.1.4.8 Language Processors

Capability exists to use intermixed Fortran-Assembly Language Code. These can be linked into one piece by the loader. The FORTRAN compiler includes ANSI options.

3.5.3.1.4.9 Libraries

Library features allow for global, compiler, macro, and user (i.e., mathematical) libraries.

3.5.3.1.4.10 Computer System Accounting

System information file includes date, time, control card, job accounting summary, site designed accounting controls, station messages, error (hardware) conditions, etc. An analysis program (part of the system) extracts and builds reports and graphs of various message types and times.

3.5.3.1.5 Environmental Requirements

The system will have the following facilities requirements:

- Space: A minimum of 2800 sq. ft. (not including work area or customer engineering office space).

- Cooling: 325,765 BTU/Hour air dissipation
422,125 BTU/Hour chill water dissipation

- Power: 1 - 25 KVA motor generator
1 - 40 KVA motor generator

127 KVA 60-cycle power for individual devices.

3.5.3.1.6 Cost Estimate

\$11 to \$12 million.

3.5.3.2 IBM S/370 MP/M 168 Computer System

The IBM Computer System consists of three S/370 M 168 main frames, each with 2 million bytes of processor storage. Two main frames are connected together by a 3068 Multi-System Unit, which creates an MP 168 computer configuration with 4 million bytes fully shared memory. See Figure 3.5.3.2-1.

It is anticipated that the MP 168 will be the computational element used for the fixed base crew station and the time sharing system; the single M 168 will be used for the motion base crew station.

The majority of the peripheral equipment may be switched between each computer element, allowing a large degree of flexibility in the event of a failure in any single piece of equipment.

3.5.3.2.1 Host Computer System• MIP Capacity

- Each M 168 main frame can execute in excess of 4.0 MIP.
- 3-M 168's will have in excess of 12.0 MIP.

• Word Size

- 32-bits

• Fixed Point

- Single Precision - sign + 31 bits
- Double Precision - sign + 63 bits

• Floating Point

	<u>Sign</u>	<u>Exp</u>	<u>Fraction</u>
- Single Precision	1	7	24
- Double Precision	1	7	56
- Extended Precision	1	7	112

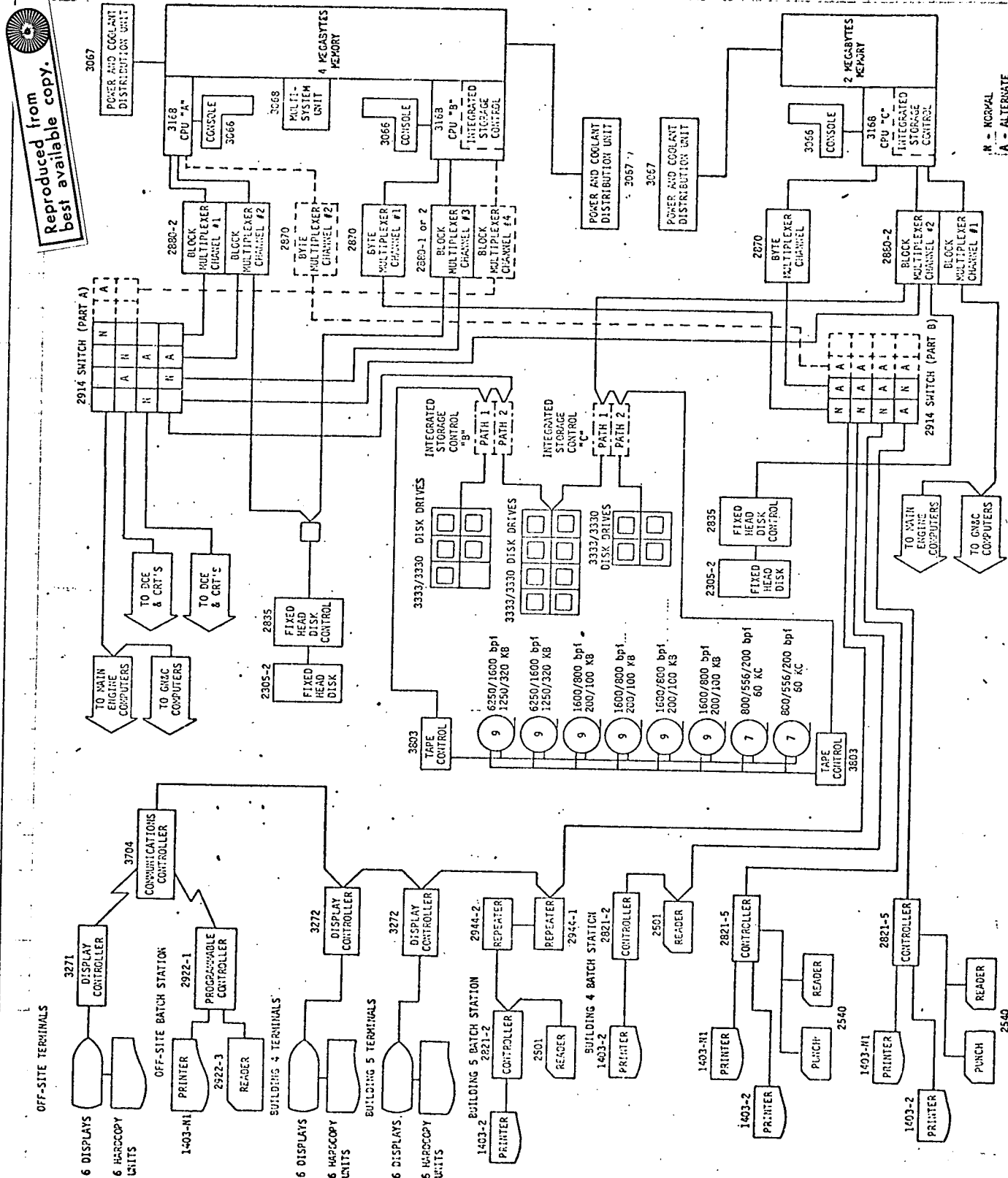


Figure 3.5.3.2-1

IBM S/370 - H2/M 168 COMPUTER SYSTEM

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• Registers

- 16 general purpose (Fixed Point, 32-bits)
- 4 Floating Point (64 bits)

• Instruction Set Class

- Load/Store
- Arithmetic
 - Binary
 - Decimal
 - Floating Point
 - Fixed Point
- Logical
- Test/Branch
- Search/Compare
- Shift
- Index
- Byte/String Manipulation
- Supervisory

• Storage

- Buffer storage
- 80 ns cycle time
- 4 parity bits/words
- 8K bytes expandable by 8K to 16K

• Processor Storage

- 1 Million bytes, expandable to 8 million bytes in 1 million byte increments.

- 4 way double word interleaved access

- 8 byte wide data path
- Read/write cycle time of 480 ns for 8 bytes on double word bound.
- Partial write time of 800 ns.
- CPU data fetch (double word) takes 560 ns.
- In cases of simultaneous memory requests to same storage module, satisfaction is based upon requesting priority at storage control unit.
- Error checking and correction code.

3.5.3.2.2 Central Processing Unit

• Features

- 4 deep instruction stack
- A double word from instruction stream can enter instruction buffers every 80 ns.
- Dynamic address translation allowing virtual storage to 16 million bytes.
- High speed multiply feature.
- Automatic instruction retry.
- Time of day clock.
- Store and fetch protection.
- Writable and read only control storage.
- Integrated storage control.

3.5.3.2.3 Time Sharing Equipment

• 3271 Display Controller

- Buffer capable of handling devices of up to 1920 characters.
- Can attach up to 32 separate I/O devices.
- Permits transmission speeds of 1.2K, 2.0K, 2.4K or 4.8K BPS.
- Permits remote attachment to S/370.

• 2922-1 Programmable Controller

- Contains 8K bytes of addressable program and data storage.

Each byte can store alphanumeric, binary or logical data.

- Provides eight general registers, including direct addressing capability.

- Operates with fixed point and packed decimal arithmetic.

Included are multiply, divide, edit and translate instructions.

- All functional switches and lights are located on the controller console.

• 2922-3 Card Reader

- Provides card input for the controller at speeds up to 500 cards per minute.

- Can read all EBCDIC codes as well as binary cards.

- Equipped with a 1200 card hopper and 1300 card stacker.

• 3272 Display Controller

- Permits local attachment to S/370.

- Buffer capable of handling devices of up to 1920 characters.

- Provides attachment of up to 32 separate I/O devices.

- Permits speeds of up to 650KC/sec.

• 2501 Card Reader

- 600 card/minute

- Can read all 256 EBCDIC punches.

• 1403-02 Printer

- 132 print positions.

- 600 lines per minute

e 2944-1 and 2944-2 Repeater

- Physical channel extender
- Extends channel to approximately 4000 feet

3.5.3.2.4 On-Line Peripheral Equipmente 2880-2 Block Multiplexer

- Operates in selector or block MPX mode.
- Transfer rates to 3.0 MB/sec
- Channel indirect addressing.
- 2 byte interface.
- Can connect up to 8 controllers/channel
- Can attach channel - channel adaptor

e 2870 Byte Multiplexer

- Operates in byte or burst mode.
- May have selector subchannels.
- Channel indirect addressing.
- Can connect up to 8 controllers/channel.
- Can attach channel - channel adaptor.

e 3333/3330 Disk Drive

- Each pack has approximate capacity of 100 M bytes.
- Average access time - 30 ms
- Average rotational delay - 8.4 ms.
- Rotational position sensing.
- Can service multiple requests.
- Two channel switch.
- Transfer rate 806 KB/sec.

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- 2305-2 Fixed Head Disk
 - Storage capacity - 11.2 million bytes.
 - Average access time - 5.0 ms.
 - Data transfer rate - 1.5 MB/sec.
- 2835-2 Fixed Head Disk Control
 - One or two 2305-2 fixed head disks may be attached.
 - Rotational position sensing.
 - Two channel switch.
 - Can service multiple requests.
- 3803 Tape Controller
 - Two channel switch.
 - Handles 7 and 9 track drives.
 - Data rates from 60 to 1250 KB/sec.
- 3420-8 9 Track Tape Drive
 - 6250/1600 BPI - 1250/320 KB/sec.
- 3420-5 9 Track Tape Drive
 - 1600/800 BPI - 200/100 KB/sec.
- 3420-3 7 Track Tape Drive
 - 800/556/200 BPI - 60 KCS
- 1403-N1 Printer
 - 132 print positions.
 - 1,100 lines per minute.
- 2540 Card Reader/Punch
 - Read 1000 cards per minute.
 - Punch 300 cards per minute.
 - Can read and punch simultaneously.

• 2914 Switch

- Connects device interface to channel interface.
- 8 device strings to 8 channels.

3.5.3.2.5 Operating System

The candidate operating system is the System/370 Operating System/Virtual Storage 2.2, which is a generally compatible extension of OS/360 MVT. VS2.2 is a virtual storage system with time-sharing and multiprocessing support integrated into the control program. In addition, the design provides the potential for the concurrent execution of time-sharing, background, and real-time jobs.

• Overhead

The amount of real memory and CPU time used will be dependent upon the options selected and services used. A reasonable estimate of resources used would be 10 - 15%, time and core (i.e., ~.4 MIP, 300K Bytes).

• OS/Simulation Software Interface

The VS2.2 operating system provides most of the required system facilities and services to implement the simulation software system. Facilities and services that must be added, (e.g., special device support), may be installed using standard features of the system.

• Synchronization of Parallel Execution

VS2.2 contains all necessary logic and controls to fully integrate a two CPU complex into one total computer resource. This is accomplished by having each CPU execute one common operating system. Thus each CPU is fully aware of the actions and status of the other CPU.

• System Synchrony

- Interval Timer

This timer provides program interruption on a program-controlled

basis. The timer, which is updated by timing circuits, has a time resolution of 3.333 milliseconds.

- Time-of-Day Clock

The clock's binary value, updated each microsecond, can be interrogated or set by provided instructions.

- Clock Comparator and CPU Timer

The clock comparator causes an external interruption when the time-or-day clock reaches a value specified by the user.

- Priority Structure

VS2.2 supports a complete multi-level priority structure throughout the system. This structure may be dynamically modified by the user programs.

- Global and Common Reference

The standard compilers and program products, (e.g., PL/I) provide for global and named common data areas.

- Link Edit or Collection

- Linkage Editor

The linkage editor combines separately compiled or assembled object modules into a single program that is ready to be loaded and executed. It also combines previously edited load modules with each other or with object modules, and enables changes to be made in a program without recompiling (or reassembling) the complete program; only those sections that are changed need to be recompiled.

- Interrupt Structure

The computer interruption system separates interruptions into five classes:

Supervisor Call interruptions are caused when the program issues an instruction to pass control to the part of the control program which performs the supervisory functions associated with a task.

Program interruptions are caused by various kinds of programming errors and exceptions.

Machine Check interruptions are caused by the machine-checking circuits detecting an error.

I/O interruptions are caused by and I/O unit ending an operation or otherwise needing attention.

External interruptions are caused by an external device that requires attention, by the interval timer going past zero, or by the operator pressing the interrupt key. Provision is made for user handling of external interrupts.

- Program Residency/Non-Residency

Executable user program segments which cannot be accommodated in the real memory of the user's system may be loaded into real memory for execution via the VS2.2 demand paging function, giving the computer the appearance of having 16 m bytes of storage, standard VS2.2 overlay facilities, or a user written overlay handler.

- Language Processors

- VS2.2 system assembler

A macro assembler which translates a symbolic language into machine language relocatable object code.

- Fortran IV

- System Utilities

An extensive library of facilities and services are provided by utility routines to simplify and enhance utilization of the system.

- Mathematical Library

A comprehensive library of mathematical subroutines are supplied in the Fortran IV library. This library also includes input/output support routines for use by fortran programs.

- Macro

A macro library providing access to the complete VS2.2 system capabilities is supplied. The ability to add installation defined macro's is inherent in the library.

- Computer System Accounting

- Two standard measurement facilities are included in VS2.2:

- System Management Facilities (SMF) provide the means to gather and record information that can be used for user accounting or for evaluating system use. SMF is basically job and terminal-session related.

- The system activity Measurement Facility (MF/1) collects information about system activity and produces trace records and reports. MF/1 is basically system-oriented; it is designed to aid the installation in improving system performance, analyzing system trends, and evaluating future system requirements.

3.5.3.2.6. Environmental Requirements

- Electrical Requirements

- 250 KVA

- Cooling Requirements

- Air 700,000 BTU/HR

- Chilled water 500,000 BTU/HR

- Floor Space

- 4,000 Sq. Ft.

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3.5.3.2.7 Cost

- \$13 to \$14 million.

3.5.3.3 UNIVAC 1110 Computer System

The Univac Computer System shown in Figure 3.5.3.3-1 is comprised of two central complexes (System I, System II), each of which is a Univac 1110 Computer. Both computers have identical characteristics with respect to computational power and addressable core storage. The on-line peripherals have been configured so that each computer has full access capability via transfer switches. These transfer switches have also been utilized in the configuring of the remote batch stations, interactive terminals, and the essential hardware elements of each crew station.

3.5.3.3.1 Computer System(s)

• MIP Capacity: 6.0 (System I)

6.0 (System II)

TOTAL: 12.0

• Word Size: 36 Bits

• <u>Floating Point</u>	<u>Sign</u>	<u>Exponent</u>	<u>Fraction</u>
Single Precision	1 Bit	8 Bits	27 Bits
Double Precision	1 Bit	11 Bits	60 Bits

• Fixed Point

Single Precision Sign Bit + 35 Bits

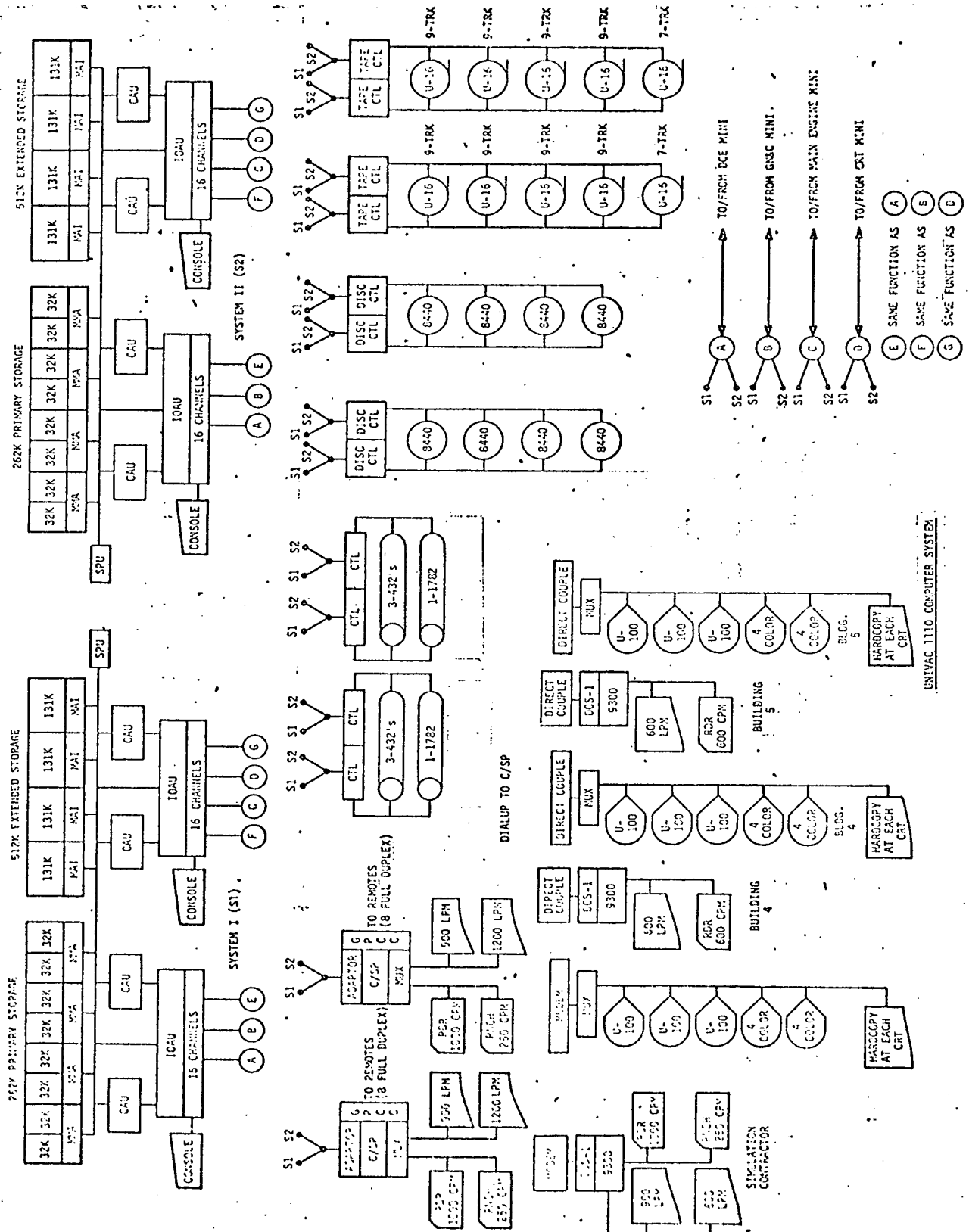
Double Precision Sign Bit + 71 Bits

• Primary Storage (PSU): 262K (System I)

262K (System II)

TOTAL: 524K

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UNIVAC 1110 COMPUTER SYSTEM

FIGURE 3.5.3.3-1

Features:

- 280 nanosecond read
- 480 nanosecond write
- 650 nanosecond partial write
- Word size = 36 bits
- 8,142 word memory
- Simultaneous access to each module in a storage unit
- Parity Checking
- Access through each MMA by up to four CAU's and four IOAU's
- Expandability in 32K word increments up to a maximum of 262K words
- Interleave access (odd-even addressing to two adjacent 8K modules)
- Access conflicts resolved for 8K word modules
- Partitionable in 32K word increments

• Multiple-Module Access (MMA) Section

Features:

- Provides eight priority - ordered connection paths to each of the storage modules in the PSU.
- Number of paths may be expanded to 16.
- Each CAU requires two paths (operand and instruction)
- Each IOAU requires one path
- The basic MMA contains four preemptive paths for IOAU use and four non-preemptive paths for CAU use.
- MMA expansion paths are non-preemptive only.

• Extended Storage (ESU)

512K (System I)

512K (System II)

TOTAL:1024K

Features:

- 1.5 psec read/write/partial write cycle time
- 131K words/unit
- Expandable to 8 units (1M word) per system
- Parity checking for data, address information and read/write control information
- Connected via the MAI to the CAU and IOAU

• Multiple Access Interface (MAI)

Each MAI module operates in the same manner as the MMA. One MAI is required for each ES unit.

• Command/Arithmetic Unit (CAU)

Features:

- 4-deep instruction stack
- Interface capability: 4 PSU's (via MMA's)
8 ESU's (via MAI's)
- Overlapping and interleaving of data paths
- Can logically be removed from system for maintenance without affecting the remainder of the system
- CAU to CAU communication via interprocessor interrupt lines
- One CAU can interface with two input/output access units
- 300 nanosecond effective basic instruction time

- MIP rate: 1.4 - 3.0/CAU

- Input/Output Access Unit (IOAU)

Features:

- Provides control and data paths between main storage and peripheral subsystems.
- Allows data transfer to occur without affecting the instruction cycles of the CAU.
- Minimum of eight channels.
- Expandable in increments of eight to 24 channels.
- Data chaining provided scatter/read, gather/write
- Interfaces to CAU, storage, system partitioning unit (SPU), peripheral subsystems.
- Aggregate transfer rate: 4M words/second
- Parity checking of input/output transfers

- System Partitioning Unit (SPU)

Features:

- Partitions large systems into two or three smaller systems.
- Isolates units and takes them off-line for maintenance, without disrupting the rest of the system.
- Provides system monitoring.
- Allows automatic recovery procedures.

- General Registers: 112 (36 bits/register)/CAU

- Instruction Class

Load/Store

Logical

Test/Branch

Search/Compare

Shift

Index

Arithmetic: Binary

Decimal

Floating Point

Fixed Point

Byte/String Manipulation

Supervisory

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• UNISCOPE 100 Display Terminal

The UNISCOPE 100 Display Terminal is an alphanumeric display that is designed for a broad range of applications which require direct operator interaction with a centralized computer system. Due to its modular construction, the UNISCOPE 100 terminal operates either as a data entry or as a display device.

3.5.3.3.2 Time-Sharing• The UNISCOPE 100 Terminal

The UNISCOPE 100 Terminal is a self-contained unit consisting of a cathode-ray tube display screen, refresh memory, character generator, control logic, operator keyboard, and communications interface. Special interfaces for direct computer connection and hard copy output are also available. A variety of presentation formats are offered which provide a total display capacity of 480, 512, 960, or 1024 ASCII characters. The complete ASCII set of 96 characters can be displayed (includes upper and lower case alphabets). Hardware editing capabilities enable the operator to completely edit any message prior to transmitting the message to the computer.

Sixteen UNISCOPE 100 terminals may be connected to a single communications line modem or to a computer input/output channel by means of multiplexers.

• Remote Batch

Simulator Contractor Site

- 1 9300 Processor (8K bytes storage)
- 1 Printer 600 LPM
- 1 Printer 900 LPM
- 1 Reader 1000 CPM

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- 1 Punch 250 CPM
- 1 Data Communications Subsystems (40.8 KBPS?)

Building 4

- 1 9300 Processor (8K bytes storage)
- 1 Printer 600 LPM
- 1 Reader 600 CPM
- 1 Data Communications Subsystem 9.6 KBPS

Building 5

- 1 9300 Processor(8K bytes storage)
- 1 Printer 600 LPM
- 1 Reader 600 CPM
- 1 Data Communications Subsystem 9.6 KBPS

• UNIVAC 9300

The UNIVAC 9300 System is used as a remote subsystem to the central computer. The UNIVAC 9300 system is linked to transmission facilities through the GPCC CLT, with the transmission facilities being connected to the central computer through the C/SP.

The UNIVAC 9300 system is an internally programmed computing system which offers both an 80-column card processing capability and a high-speed magnetic tape system. The computer is equipped with all functions for execution of instructions including arithmetic and input/output control. The integral card reader, card punch, and line printer offer higher speeds than those available on the smaller UNIVAC 9200 system. The multiplexer I/O channel of the UNIVAC 9300 system can accommodate up to eight peripheral subsystems. Maximum storage size is 32,768 bytes of plated-wire storage with a cycle time of 600 nanoseconds.

3.5.3.3.3 On-Line Peripherals

• Communications/Symbiont Processor (C/SP)

General: The UNIVAC Communications/Symbiont Processor is a high performance, internally programmed system which is intended to absorb the combined symbiont functions of communications control and paper peripheral control. Its high speed internal operation and flexible I/O channels provide high throughput rates and a universal interface for all types of communications facilities and terminals.

• Processor Characteristics

The major features of the processor include the following:

- 52 half-word and full-word instructions
- Sixteen 32-bit general purpose registers, external to storage
- Attached processor maintenance panel
- I/O interrupt and data priority controls
- Interval timer (6ms resolutions)
- 16 bit data path
- Multilevel interrupt
- 630 nanosecond cycle time
- Basic binary add (RX) instruction time of 2.52 ps (four cycles)
- Binary add instruction (RR) time of 1.26 ps (two cycles)

• Interrupts

The interrupt system provides an automatic means of alerting the C/SP processor to exceptional or unexpected conditions, such as the end of the I/O operations, program errors, machine errors, and similar occurrences and directs the processor to the appropriate program routine following their detection.

Storage• Main Storage Characteristics

The main features of main storage include the following:

- Capacity: 32,768 bytes minimum; 131,072 bytes maximum
- Cycle time: 630 nanoseconds read/write/cycle
- Operating mode: nondestructive readout
- Storage data path: 18 bits wide (two 8-bit bytes and two parity bits)
- Addressing: zero time indexed base and displacement
double indexed
- Storage protection: program and I/O transfer
- Parity: odd parity (one parity bit per byte)

• Addressing

The addressing hardware accommodates a 17-bit address field which permits one cycle addressing of 131,072 bytes.

Channels

All information transmission in and out of the C/SP is handled by channels. The features of the C/SP channels are:

- Direct interface to storage
- Independent operation
- Simultaneous operation
- Priority interchangeability

The C/SP may contain up to seven channels, numbers 0 to 6.

Priority of these channels increases in descending channel number order, Channel 0 having the highest priority.

- Channel Types

The C/SP is equipped with the following four types of channels:

- Special Device Channel (SDC)

The primary function of the SDC is to provide the means for local program loading and maintenance of the C/SP using a serial 80 column, 80 card per minute, card reader device.

- 1100 Series Adapter Channel

The 1100 Series Adapter Channel (intercomputer adapter channel) provides an interface for direct communication between the C/SP and an I/O channel of a UNIVAC 1100 Series Computer. The maximum transfer rate is in excess of 300,000 words (36 bits each) per second.

- Multiplexer Channel

This channel provides the capability of attaching all currently available UNIVAC 9000 Series peripheral devices, which operate on a corresponding channel to the C/SP. In addition, the high speed card reader and the ASCII printer can be connected via the channel.

- General Purpose Communications Channel (GPCC)

The GPCC and associated components are described below.

- General Purpose Communications Channel (GPCC)

The GPCC performs such functions as multiplexing the various communications line terminals (CLT) so that one CLT may be serviced at a time, recognizing special characters and sequences of characters, checking character parity, coordinating all data transfers to and from storage, and executing other necessary operations.

The CLT's perform the functions of assembly and disassembly of data characters for proper reception from and transmission to a communication line, detection of certain conditions of the communication line such as loss of carrier, a ringing indication, and others; and establishment of character synchronization.

The multiplexer portion of the GPCC accepts up to 64 simultaneously presented service requests from the CLT's plus an external function (XF) request from another portion of the GPCC. The multiplexer selects one request by connecting the selected CLT to the GPCC.

• 2 Line Printers

- 2 900 LPM
- 2 1200 LPM

• Card Reader

- 2 1000 CPM

• Card Punch

- 2 250 CPM

• High Speed Drum Subsystem

	<u>Average Access</u>	<u>Capacity</u>
3 FH432 Drums	4.25 mil	4.7 million char.
1 FH1782 Drums	17.0 mil	12.5 million char.

One System Total: 17.3 million char.

Two System Total: 34.6 million char.

- Dual Access Capability
- Accessable by each central complex via transfer switch.

• Mass Storage Disc Subsystem

	<u>Average Access</u>	<u>Capacity</u>
4-8440 Disc Storage Units	30 mil.	960.3 Mil. Char.

Two System Total: 1,920.6 Mil. Char.

- Two independently addressable disc drivers per unit.
- Dual access capability.
- Accessable by each central complex via transfer switch.

• Tape Subsystems

Per System:	2 UNISERVO 16 Tape Units	1600 BPI	9-track
	2 UNISERVO 16 Tape Units	1600/800 BPI	9-track
	1 UNISERVO 16 Tape Unit	200/556/800 BPI	7-track

- Dual access capability.
- Accessable by each central complex via transfer switch.

3.5.3.3.4 Operating System (OS)

The UNIVAC 1110 system is the logical successor to the UNIVAC 1106 System and the UNIVAC 1108 Multi-Processor System. Designed to enhance the efficiency of the UNIVAC 1100 Series, the UNIVAC 1110 System offers dependable and highly effective processing in real time, demand, and batch mode, and excels in multiprocessing time-sharing applications.

• User Timer

This register is initially loaded by the program. The contents are then decremented once each 200 microseconds. A real time clock interrupt occurs when the clock count is decremented through zero. Thus, if the clock is initially loaded with the value 5000, an interrupt occurs in exactly one second.

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• Synchronization of Parallel Executions

In the proposed UNIVAC 4X2 1110 Configuration, the initiation, synchronization, and termination of execution sequences can be accomplished by special ER's (Executive Requests).

• Re-Entrant Code Generation

UNIVAC supports all forms of re-entrant processing for users of the 1100 System. The FORTRAN, COBOL, and ALGOL processors and libraries are provided as a set of re-entrant modules. The FORTRAN and COBOL compilers produce re-entrant code and can be used to produce re-entrant processors for local use.

• System Synchrony

Real-time clock

- A user-written ER (Executive Request) can be written and included in the set of ER's for: initializing the Real Time Clock with a time-value and receiving an interrupt when the time-value is expended.

- A special ER (RT\$) allows alteration of priorities of program modules.

- Priority Structure: 1100 Operating System supports a complete multi-level priority structure throughout the system.

• Link Edit or Collection

The UNIVAC 1100 Series Operating System provides the ability to combine the relocatable elements generated by a language processor into an executable (absolute) element. This combination or collection of relocatable elements is done by a system processor, the collector.

• Interrupt Structure

Specific interrupt locations are assigned within the lower addresses of a main or extended storage module as specified by a 9-bit module select register (MSR). These interrupt locations are programmed to capture the interrupted address and enter interrupt response subroutines in the executive system. The synchronization of input/output activities and response to real time situations are accomplished through some of these interrupts.

Other interrupts are provided for certain error conditions detected within a CAU or IOAU. These may result from a programming fault such as an illegal instruction, a storage parity error, or a user program violations such as an attempt to write into a protected area of storage or a violation of guard mode.

• Program Residency/Non-Residency

1100 Operating System supports two levels of program segmentation. One level is the classical overlay segment which physically, via I/O, replaces part of an existing program. The program bank concept provides a virtual storage mechanism for the 1100 series programmer. The Executive System in this manner currently supports a virtual space of nearly 67 million 36-bit words (over 267 million bytes). Half of the banks are available to the programmer for the individual program and the other half is reserved for common routines including the re-entrant subroutines libraries. Each bank (segment) may be specified as static (always available) or dynamic (load on request). Static banks are kept resident in memory any time the program is active, Dynamic banks are loaded upon request, and if

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space is needed, are the first to be removed from memory when the program is no longer accessing them. This form of segmentation preserves the contents of a segment when a new segment is accessed, which is not the case for overlay segments. The 1110 hardware provides bank referencing instructions which operate as subroutine call instructions in that they provide for return to the calling bank.

In the 1110 System, four of the possible 510 banks are accessible at any given time without requiring use of the bank referencing instructions.

• Language Processors

- The UNIVAC 1100 Series Assembler

The UNIVAC 1100 Series Assembler translates a symbolic language composed of brief expressions to machine-language relocatable object coding for the UNIVAC 1110 System.

- FORTRAN V

FORTRAN V has all the features of the proposed American National Standard FORTRAN IV language plus many valuable extensions which significantly increase the power and flexibility of the language, particularly in the areas of data handling.

- Libraries (System Utilities)

The system includes a set of auxiliary processors which perform functions that complement those of the source language processors such as FORTRAN, COBOL and Assembler. This set of processors includes the Collector for linking relocatable subprograms, the Procedure Definition Processor for inserting and modifying procedure definitions in a library,

the ELT Processor used to insert elements, the Data Processor to introduce data descriptions. A comprehensive set of library elements complements these processors.

Included within the Utilities section of the Executive System are diagnostic routines, program file manipulation routines, file utility routines, and cooperative routines which aid the user by performing such functions as reading cards, printing line images, transferring files from device to device, and carrying out housekeeping functions required for file-residence on mass storage devices.

- Math-Pack

Math-Pack provides the UNIVAC 1110 System with a comprehensive library of 84 fundamental mathematical subprograms coded in FORTRAN V.

- Stat-Pack

Stat-Pack provides the UNIVAC 1110 System with a comprehensive library of 91 fundamental statistical subprograms coded in FORTRAN V.

- Macro

Extensive macro capability (Procedures or PROCs) is an integral capability of the Assembler.

• Computer System Accounting

To facilitate examination of user environment, UNIVAC provides a system within the Operating System to collect data during operation.

This performance measurement system is the Software Instrumentation Package (SIP).

SIP consists of a set of routines within the Executive which collects data, and a series of user-level data reduction programs. Statistics

are gathered on such things as CPU, storage and I/O channel utilization, file placement and accesses, etc.

• C/SP Software

The software support provided for the C/SP is designed to provide complete flexibility for implementing a symbiont subsystem and for handling communications configurations with all types of terminal hardware while maintaining an expedient user interface. Coding efficiency, is achieved by the utilization of a powerful instruction set at the assembly level. System macros are also provided to facilitate the user's requirements.

Software to integrate the UNIVAC C/SP effectively with the host computer system is supplied; an assembler and simulator to write and debug user own code on the larger system also are included.

The software package is divided into three segments: (1) resident programs and routines; (2) programs to operate under the host computer executive system; and (3) modification to host computer elements.

Each of these segments is discussed in further detail in the following paragraphs.

- Resident Programs

The resident program software elements are defined as programs which reside entirely or partially in C/SP main storage during their execution. Resident programs include:

Operating System

Diagnostic Routines

Intercomputer Handler

- Operating System

The UNIVAC C/SP Operating System comprises various program

modules which are specified by the user at system generation. When supplied elements are used, the following are included:

- Terminal Management Supervisor (TMS)
- Message Control Program (MCP)
- Terminal Management Control Routine (TMCR)
- Communication Control Routines (CCR)
- Symbiont Control Program (SCP)

3.5.3.3.5 Environmental Requirements

- Electrical Requirements in KVA

- Non-regulated 208 V, 3Ø TOTAL: 244.0

- Air Conditioning

- BTU/Hr. 771,054

- CFM 67,714

- Approximate Floor Space

- 5428 sq. ft. per system X 2 = 10,856 (gross estimate should be less).

3.5.3.3.6 Cost Estimate

\$11 to 12 million

3.5.3.4 Xerox Sigma 9 Computer System

The Xerox Computer System consists of three computer complexes:

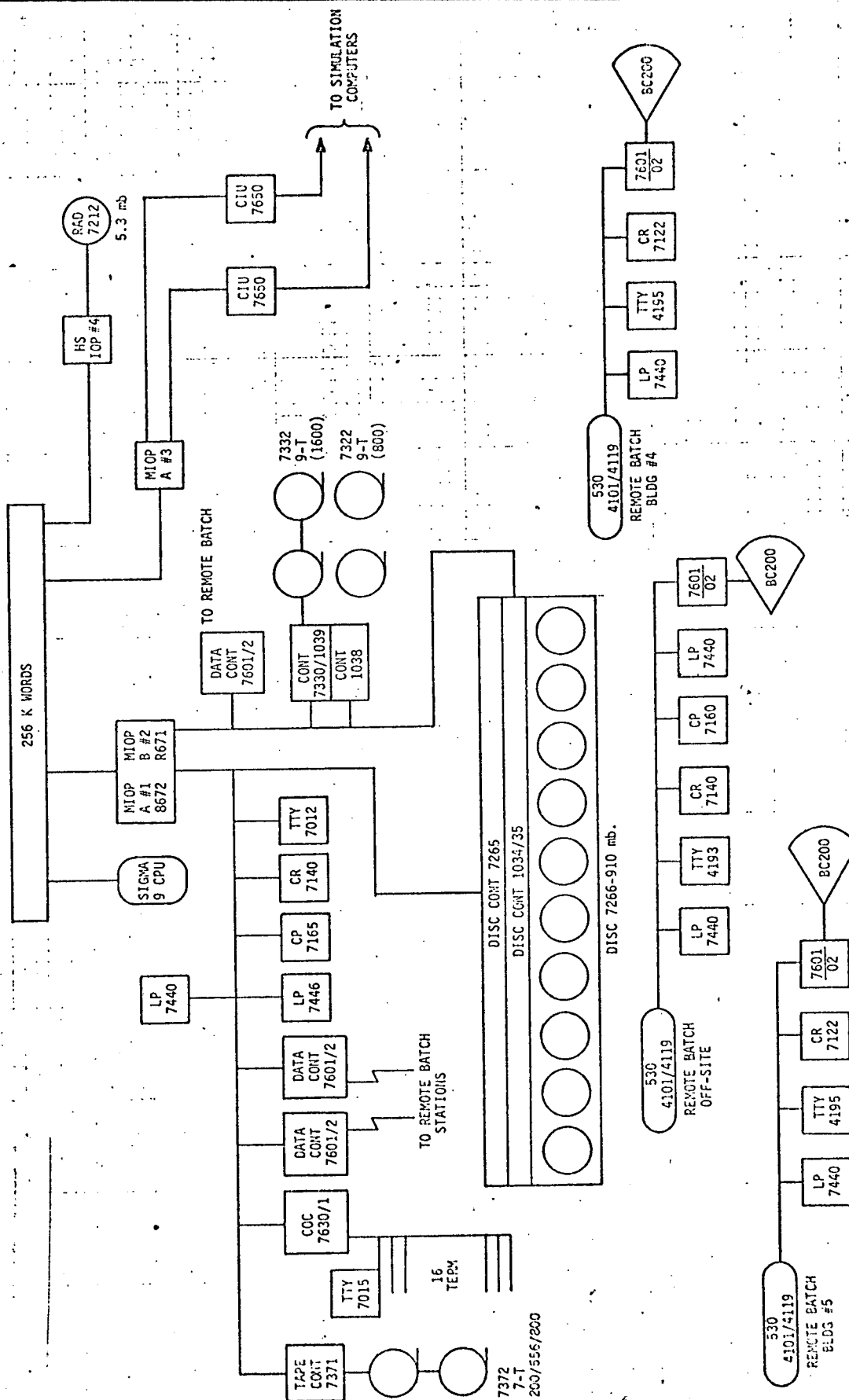
- One for the motion base crew station.
- One for the fixed base crew station.
- One to process the time-sharing and remote batch demands.

The hardware organization of each complex is depicted in Figures

3.5.3.4-1 and 3.5.3.4-2.

3.5.3.4.1 Typical Sigma 9 Host Computer

- Computational rate - 0.8 MIP
- Access/Cycle Time - 900 nanoseconds
- Overlap Capability - three (3) instruction look-a-head
 - no cycle stealing I/O
- Arithmetic precision
 - Word length: 32 bits
 - Fixed point range: -2^{31} to $2^{31} - 1$
 - Floating point single precision: Fraction $\times 16^{-64}$ - 16^{63}
6 digits
 - Floating point double precision: Fraction $\times 16^{-64}$ - 16^{63}
14 digits
- Instruction Repertoire
 - Load/Store
 - Binary
 - Decimal
 - Floating Point
 - Fixed Point
 - Logical



XEROX SIGMA 9 TIME SHARING COMPUTER SYSTEM

FIGURE 3.5.3.4-1

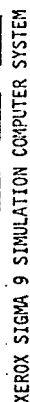


FIGURE 3.5.3.4-2

- Test/Branch
- Search/Compare
- Shift
- Index
- Byte/String Manipulation
- Supervisory

- Registers: 16 general purpose
- Extensive Interrupt Structure

Memory Hierarchy

- Main Memory (all executable)

- Size
 - 512K words (2048K bytes)
- Speed
 - 900 nanoseconds
- Type
 - Core

- Sigma does not support bulk or non-executable storage.

Configuration Features

- Reconfiguration

Sigma is a flexible hardware system. A total reconfiguration capability (e.g., switching of CPU buses, I/O channel assignments, etc.) can be provided.

- All Sigma computers and peripheral products are totally upward compatible.

- Redundancy

A totally redundant system has been configured which emphasizes ease of failover.

• Multipathing

Sigma is designed as a multi-path system. Each CPU has its own data path to memory as does all I/O processors.

3.5.3.4.2 Time-Sharing Equipment

Xerox provides an entire line of communication products including concentrators, front ends and RJE terminals. Items of interest include:

• Remote Job Entry

- Intelligent terminal

Xerox 530

- DCT2000, 225 LPM

250 CPM, 2251 LPM

• Interactive Devices

- Teletypes

10 CPS

- BC100, BC200

Display Terminal, 8-color option, up to 9600 BAUD

3.5.3.4.3 On-Line Peripheral Equipment

• Magnetic Tapes

- 9 track, 1600 BPI, 120KB and 240KB

- 9 track, 800 BPI, 60KB and 120KB

- 7 track, 200/556/800 BPI, 60KB

• Removable Disk - High Density

- 91 Mega byte drive, 41.5 ms access, 513 KB

• Fixed - Head Disk

- 6.2 + Mega byte unit, 17 ms access, 384KB

- 5.3+ Mega byte unit, 17 ms access, 3.2KB

- Card Readers - 80 column, 1500 CPM, 400 CPM
- Card Punch - 80 column, 300 CPM, 100 CPM
- Line Printers - 132 print positions, 600 LPM, 1100 LPM, 1500 LPM

Operator Interface

- Console - Teletype, 10 CPS
- Maintenance Panels - included in hardware
- Time of Day - Displayed every minute upon operator's console

3.5.3.4.4 Operating System - Control Program - Five (CP-V)

The core requirements for CP-V including system residency, system buffers and transient areas is 32K words. Based on the identified requirements, the worst case overhead for CP-V in terms of instructions per second is .2 MIPS when executing on a Sigma 9.

CP-V will provide a hospitable environment for real-time simulation software.

System Synchrony

- CP-V allows the user to access and control up to two (2) real-time clocks. Each clock can be individually set to any of four manually switchable frequencies: The commercial line frequency, 500_{HZ}, 2000_{HZ} or a user supplied frequency.

- User programs can establish and receive interrupts based on time intervals using the M:STIMER facility of CP-V.

- User programs have the capability to initiate and synchronize the execution of additional program modules through the GHOST job facility of CP-V.

• CP-V provides for dynamic altering of execution priority for a task based on the functions currently being performed by that task (I/O, compute bound).

• CP-V provides a sophisticated priority structure for execution based on that task's mode of operation (batch, interactive and real-time). The selection priority for mode of operation is defined at system generation time, but can be altered dynamically by the operator.

• The Sigma architecture provides an extensive interrupt structure for the monitoring of external events. CP-V provides software support for controlling of interrupts so as to prevent loss of data. CP-V also allows the user to directly service selected interrupts if he so desires.

Global and Common References

• Most of the language processors which operate under CP-V allow the user to declare external definitions and references in his program.

These include the following processors:

- Xerox Extended FORTRAN IV
- Xerox ANS COBOL
- Xerox META Symbol
- Xerox SL-I
- Xerox FMPS
- Xerox Data Management System

• The ability of program modules to share common data is provided by the various Xerox language processors.

The Xerox CP-V operating system provides a sophisticated

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linkage-editor processor called a LOADER which allows the user to combine discrete software segments into executable modules. Xerox language processors generate object code such that routines written in different languages can be combined to form a single executable load module (i.e., a FORTRAN main program may have subroutines written in COBOL, FORTRAN, and META-SYMBOL (Assembler)).

Interrupt Structure

- The Sigma 9 provides a very extensive interrupt system including eight internal and fault interrupts, twelve traps (program faults), two (2) I/O interrupts and up to 224 external interrupts. These interrupts are controlled through an elaborate system of arms, disarms, enables, and disable flip-flops.

- Up to four real-time clocks are a part of the interrupt system and can be monitored by either the user or CP-V.

- The handling of internal and fault interrupts is reserved for CP-V. The user has the ability to handle all external interrupts or let CP-V handle them.

- The I/O system of CP-V allows the user the option to perform I/O with either wait or no wait specified. The no wait option allows the user to maintain control of the CPU instead of being forced to relinquish it upon initiation of I/O.

The CP-V supports both the paging or virtual memory technique and the overlay technique. The virtual memory support is CP-V's native mode and enhances total system performance and throughput.

Language Processors

- Xerox extended FORTRAN IV - (ANSI is a subset)

- Xerox META-Symbol (assembler)
- Xerox ANS COBOL
- Xerox Data Management System (data base)
- Xerox SL-I (continuous system simulator)
- Xerox FMPS (linear programming package)

The FORTRAN Language Processor allows the user the ability to insert symbolic code (assembly language) statements within his FORTRAN statements.

CP-V provides a host of libraries for the user. Included is a system utility package providing file and system maintenance routines. A complete statistical and mathematical library is available from the Xerox User's Group. To aid the user in using system procedures, a complete Macro library is available. User libraries are easily created and maintained.

CP-V provides comprehensive statistical gathering packages.

Not only are standard user accounting statistics available (job execution time, resource usage summaries) but also statistics reflecting total system usage (I/O rates, I/O volume, CPU utilization, processor utilization, etc.).

This information is made available to the installation in a file and may be accessed on-line or in batch. Also available to the installation is a series of programs which runs analysis on these statistics and helps the installation to better their system.

3.5.3.4.5 Environmental Requirements

- Space
 - A maximum of 5550 sq. ft. will be required.
- Cooling
 - 1,455,300 BTU/Hour air dissipation

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• Power

- 488.8 KVA

3.5.3.4.6 Cost Estimate

\$10 to \$11 million

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4.0 Study Results

4.1 Software Development Plan

The SMS software development plan is presented in Figure 4.1.

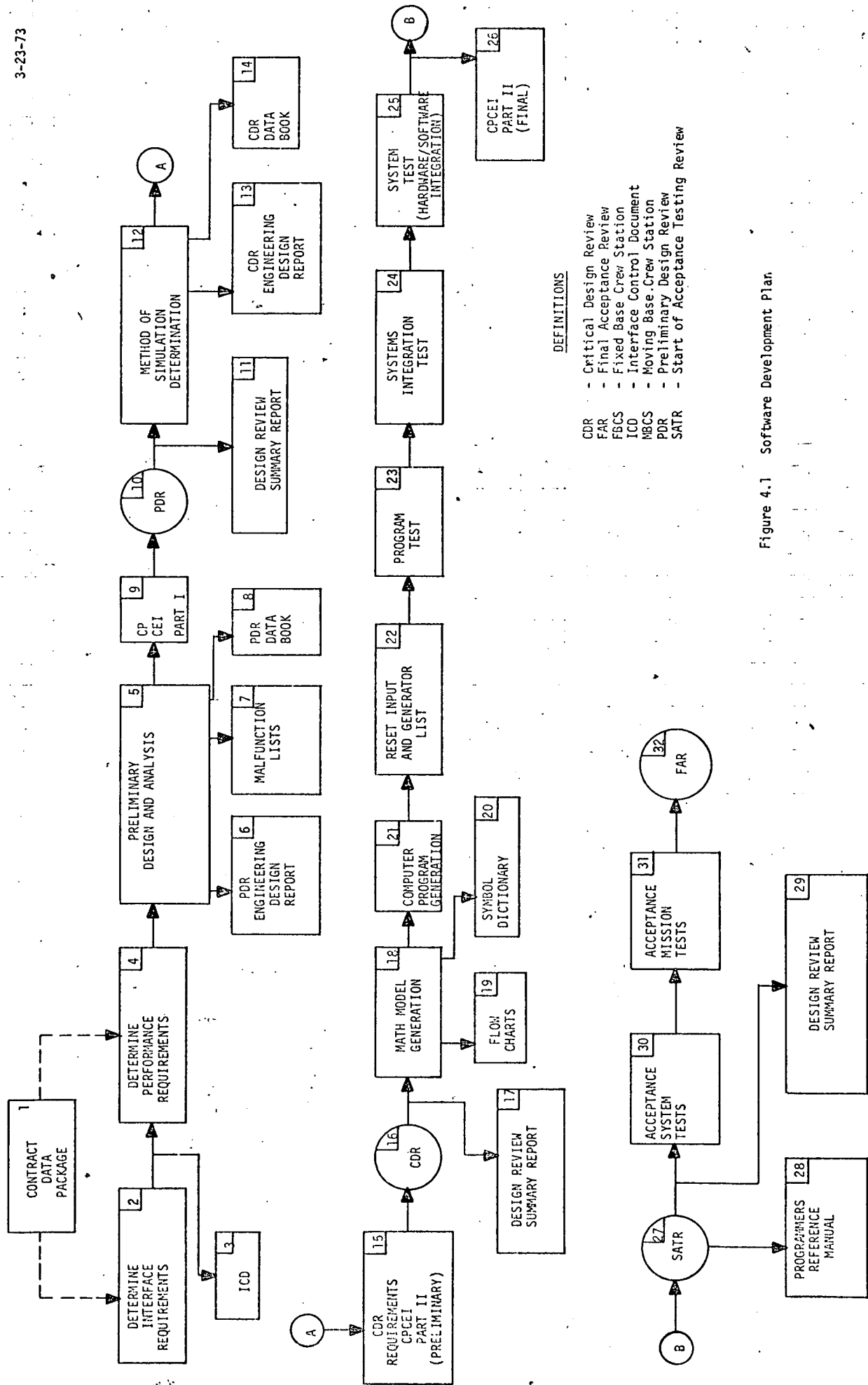


Figure 4.1 Software Development Plan.

4.2 Software Development ScheduleMBCS

<u>Month</u>	<u>DRL</u>	<u>Activity/Milestone</u>	<u>Plan Block</u>
0	--	Authority to Proceed	--
	--	Contract Data Package	1
3	22	PDR Engineering Design Report	6
	--	Malfunction Lists	7
	34	PDR Data Book	8
	32	Interface Control Document	3
	40	CPCEI (Part I)	9
4	--	PDR (MBCS)	10
	39	Design Review Summary Report	11
7	22	CDR Engineering Design Report	13
	34	CDR Data Book	14
	41	CPCEI (Part II) Preliminary	15
8	--	CDR (MBCS)	16
	39	Design Review Summary Report	17
24	41	CPCEI (Part II) Final	26
25	--	SATR (MBCS)	27
	31	Programmers Reference Manual	28
	39	Design Review Summary Report	29
26	--	FAR (MBCS)	32

FBCS

20	--	Authority to Proceed	--
	--	Contract Data Package	1
23	22	PDR Engineering Design Report	6
	--	Malfunction Lists	7
	34	PDR Data Book	8
	32	Interface Control Document	3
	40	CP CEI (Part I)	9
24	--	PDR (FBCS)	10
	39	Design Review Summary Report	11

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<u>Month</u>	<u>DRL</u>	<u>Activity/Milestone</u>	<u>Plan Block</u>
26	22	CDR Engineering Design Report	13
	34	CDR Data Book	14
	41	CPCEI (Part II) Preliminary	15
27	--	CDR (FBCS)	16
	39	Design Review Summary Report	17
39	41	CPCEI (Part II) Final	26
40	--	SATR (FBCS)	27
41	--	FAR (FBCS)	32

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4.3 Risk Evaluation

4.3.1 Software

Results of the SCD indicate that practical methods of simulation are available without a necessity of new technique development. In most cases, a number of concepts can satisfactorily fulfill the requirements at approximately the same cost. In others, the cost trade-offs and desirability of the method for training requirements is not too obvious due to lack of detailed data. The conceptual designs could change as more analysis is made and/or more data becomes available.

4.3.2 Computer Complex Configurations

The candidate computer complex configurations defined in Section 3.5 of the SCD are operative with respect to the simulation and time-sharing requirements of the SMS. Further detailed evaluation of these configurations, both hardware and software, will be made during the base-line definition phase of the SMSS Study.

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APPENDIX A

SSME SIMULATION REQUIREMENTS

- I. Temperature Limit Control Range and Nominal Control Point Values
- II. Engine Limit Control Shutdown Parameters
- III. Failure Mode Identification
- IV. Vehicle To Engine Commands
- V. Engine Status Transmitted to Vehicle
- VI. Status/Recorder Data Transmitted to Recorder
- VII. Vehicle/Engine Command Code Format
- VIII. Engine Status Word
- IX. Sensor Ranges
- X. Sensor Data Reasonableness and Comparison Test Requirements
- XI. Flight Sensor Data Processing Functions
- XII. Malfunction Mode Identification and Responses
- XIII. Operational Function Requirements for Start Preparation
- XIV. Propellant Conditions Required for Engine Ready Status Signal
- XV. Operational Function Requirements for Engine Start Sequence
- XVI. Operational Function Requirements for Engine Shutdown Sequence from Mainstage
- XVII. Operational Function Requirements for Propellant Dump
- XVIII. Operational Function Requirements for Abort Turnaround
- XIX. Operational Program Operating Mode Definition

These tables have been extracted from North American Rockwell documents RC1007, RC1010, and 13M15000F. The tables have been given new numbers for clarity within this document.

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TABLE I
TEMPERATURE LIMIT CONTROL RANGE
AND NOMINAL CONTROL
POINT VALUES

	Minimum Control Point Capability	Nominal Limit Control Point	Maximum Control Point Capability	Notes
High Pressure Fuel Turbopump Turbine Dis- charge Temp - R	1600	1895	2200	1
High Pressure Oxidizer Turbopump Turbine Discharge Temp - R	1750	2040	2350	1

Notes

- 1 Temperature limit control logic is to function so as to prevent either of these temperatures from exceeding the control point setting by more than 50 R for more than 0.5 second.

TABLE II
ENGINE LIMIT CONTROL SHUTDOWN PARAMETERS

PARAMETER	SENSOR	RANGE OF LIMIT SETTINGS(3)			NOTES	REMARKS
		MINIMUM SETTING	NOMINAL SETTING	MAXIMUM SETTING		
		SETTING	SETTING	SETTING	TOLERANCE	
High Pressure Fuel Turbo-pump Turbine Discharge Over Temperature	Temperature-R	1650	1945	2250	±50	1, 2 Temperature spike above this level limited to 0.5 sec.
High Pressure Oxidizer Turbo-pump Turbine Discharge Over Temperature	Temperature-R	1800	2090	2400	±50	1, 2 Temperature spike above this level limited to 0.5 sec.
High-Pressure Fuel Turbopump Shaft Speed	Shaft Speed-RPM	26000	33300	40000	±200	2 Reduced design safety factor at speeds exceeding the limit.
High-Pressure Oxidizer Turbo-pump Shaft Speed	Shaft Speed-RPM	22000	28700	35000	±200	2 Reduced design safety factor at speeds exceeding the limit.
Combustion Chamber Pressure (Low)	Chamber Pressure-WNPL	20	40	60	±1	4 Requires three consecutive samples below this level.*
Combustion Chamber Pressure (High)	Chamber Pressure-WNPL	90	112	120	±2	4 Requires three consecutive samples above this level.*

TABLE II
(CONT)

PARAMETER	SENSOR	RANGE OF LIMIT SETTINGS (3)			REMARKS
		MINIMUM	NOMINAL	MAXIMUM	NOTES
		SETTING	SETTING	SETTING	TOLERANCE
Oxidizer Heat Exchanger Failure	High-Pressure Oxidizer Discharge Pressure and Heat Exchanger Outlet Pressure- Psid	300	575	750	±10
Loss of High Pressure Oxidizer Pressure- Psia	Purge	20	40	80	±2
Turbopump Intermediate Seal Purge					

* Controller switches to a high sample rate (200 samples/second) to verify data in timely fashion and to reduce time to shutdown initiation.

Notes

1. Temperature spike allowed above this level for a nominal 0.5 second, adjustment range of minus 0.5 to plus 1.0 second.
2. This limit shutdown logic to be activated when closed loop thrust control is activated.
3. Limit Settings shall be alterable within the indicated ranges of settings by changes in software program data constants.
4. This limit shutdown logic to be activated as defined in RC1010.
5. This limit shutdown logic to be activated at all times during start and mainstage phases of engine operation.

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TABLE CHECKOUT TESTS

For general test conditions and requirements, see Notes 1 and 8.

PART A: CONTROLLER SELF TEST

Controller self test shall include all test functions which can be accomplished without controller initiated transmission of control signals across the controller to engine interface. The test shall specifically verify all computer functions.

Failure Mode Identification No. (Note 4)	Failure Identification Name	Description of Test	Acceptable Performance Criteria	Failure Parameter Name
--	-----------------------------	---------------------	---------------------------------	------------------------

φ 1	Controller Channel 1	Controller Self Test Controller No. 1 - Tests TBD	TBD	TBD
-----	----------------------	---	-----	-----

φ 2	Controller Channel 2	Controller Self Test Controller No. 2 - Tests TBD	TBD	TBD
-----	----------------------	---	-----	-----

PART B: PNEUMATIC COMPONENT AND EMERGENCY SHUTDOWN TESTS

φ 3	GN ₂ System Purge Control Valve	a. Energize GN ₂ Purge Control Valve	a. Oxidizer System Purge Pressure greater than 200 psia (Note 7) within 0.20 sec	Oxidizer System Purge Pressure
-----	--	---	--	--------------------------------

		b. De-energize GN ₂ Purge Control Valve	b. Oxidizer System Purge Pressure less than 50 psia (Note 7) within 1 sec	Same as above
--	--	--	---	---------------

φ 4	Fuel System Purge Control Valve	a. Energize Fuel System Purge Control Valve	a. Fuel System Purge Pressure greater than 300 psig (Note 7) within 0.20 sec	Fuel System Purge Pressure
-----	---------------------------------	---	--	----------------------------

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TABLE III -- (Continued)

PART B: (Continued)

Failure Mode Identification No.	Failure Identification Name	Description of Test	Acceptable Performance Criteria	Failure Parameter Name
φ 4 (cont)	Fuel System Purge Control Valve	b. De-energize Fuel System Purge Control Valve	b. Fuel System Purge Pressure less than 50 psia (Note 7) within 0.20 sec	Same as above
φ 5	Emergency Shutdown Control Valve	a. Energize Emergency Shutdown Control Valve. Energize fail-safe valves and open OPOV, FPOV, MOV, MFV. De-energize fail-safe Valves. De-energize Emergency Shutdown Control Valve.	a. OPOV starts closing first. Valves reach closed in sequence OPOV, FPOV, MOV, MFV. OPOV starts closing within 0.20 sec and MFV reaches closed within 4.5 sec.	Emergency Shutdown Control Valve Solenoid Coil Current
		b. Energize fail-safe Torque Motor Valves. Energize Emergency Shutdown Control Valve (De-energize Emergency Shutdown Control Valve and fail-safe valves when acceptable performance criteria has been verified)	b. All propellant valves open within TBD sec	Same as above
8	Liftoff Seal and Bleed Valve Control Valve	a. Energize valve	a1. Fuel Liftoff Seal and Bleed Valve Control Pressure greater than 650 psia (Note 7) within 0.20 sec	Fuel Liftoff Seal and Bleed Valve Control Pressure
		a2. Oxidizer Bleed Valve Control Pressure greater than 650 psia (Note 7) within 0.20 sec		Oxidizer Bleed Valve Control Pressure

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TABLE III (Continued)

PART Failure Mode Identification No.	Failure Identification Name	Description of Test	Acceptable Performance Criteria	Failure Parameter Name
φ 8 (cont)	Liftoff Seal and Bleed Valve Control Valve	b. De-energize valve:	b1. Fuel Liftoff Seal and Bleed Valve Control Pressure less than 50 psia (Note 7) within 0.20 sec	Fuel Liftoff Seal and Bleed Valve Control Pressure
		b2. Oxidizer Bleed Valve Control Pressure less than 50 psia (Note 7) within 0.20 sec	Oxidizer Bleed Valve Control Pressure	Oxidizer Bleed Valve Control Pressure
9	Fuel Bleed Valve	Test procedure is identical to that for Liftoff Seal and Bleed Valve Control Valve test and may be performed concurrently	a. Fuel Bleed Valve leaves closed within 0.20 sec	Fuel Bleed Valve Position
			b. Fuel Bleed Valve reaches closed within 0.20 sec	Same as above
10	Oxidizer Bleed Valve	Test procedure is identical to that for Liftoff Seal and Bleed Valve Control Valve test and may be performed concurrently	a. Oxidizer Bleed Valve leaves closed within 0.20 sec	Oxidizer Bleed Valve Position
			b. Oxidizer Bleed Valve reaches closed within 0.20 sec	Same as above
φ 11	HPOT Intermediate Seal Purge Control Valve Channel 1	a. Energize Valve Channel No. 1 Coil	Purge pressure greater than 40 psia within 0.20 sec	HPOT Inter- mediate Seal Purge Pressure
		b. De-energize Valve Channel No. 1 Coil	Purge Pressure less than 30 psia within 0.20 sec	Same as above

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TABLE III (Continued)

PART B: (Continued)

Failure Mode Identification No.	Failure Identification Name	Description of Test	Acceptable Performance Criteria	Failure Parameter Name
φ 12	HPOT Intermediate Seal Purge Control Valve Channel 2	a. Energize HPOT Intermediate Seal Purge Control Valve Channel No. 2 Coil	a. Purge pressure greater than 40 psia within 0.20 sec	HPOT Intermediate Seal Purge Pressure
		b. De-energize Valve Channel No. 2 Coil	b. Purge pressure less than 30 psia within 0.20 sec	Same as above

PART C: ACTUATORS

The test procedure for actuators shall be identical for each servo operated valve and is typified by that presented for the Main Fuel Valve. At the conclusion of the actuator tests all fail-op and fail-safe valves and the Emergency Shutdown Control Valve shall be de-energized.

Failure Mode Identification No.	Failure Identification Name	Description of Test	Acceptable Performance Criteria	Failure Parameter Name
φ 25	Main Fuel Valve Actuator Channel 1	Initial Conditions: Emergency Shutdown Control Valve energized. Fail-op valve de-energized, fail-safe valve energized coil 1 only. Coil 2 of fail-safe valve inhibited. Logic which prevents servo channel 2 to 1 transfer inhibited. MFV closed. Test Sequence: a. Ramp MFV position reference to open at 20% per second b. De-energize coil 1 fail-safe valve then step position reference to close	a. Position error less than 1% during ramp b. Valve remains open	Maximum Position Error Actuator Position Change

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TABLE III. (Continued)

Failure Mode Identification No.	Failure Identification Name	Description of Test	Acceptable Performance Criteria	Failure Parameter Name
φ 25 (Cont.)	MFV Actuator Channel 1	<p>c. Energize coil 1 of fail-safe valve</p> <p>d. Step position reference to 50% open</p> <p>e. Verify operation of Channel No. 1 servo-valve self monitoring circuits for both plus and minus servovalve spool position errors. (See Note 6)</p>	<p>c. Valve closes in 0.360 ± 0.050 sec</p> <p>d. Valve opens to 50% in 0.180 ± 0.040 sec</p> <p>e. System transfers to Channel 2 then to 1 then to 2 then 1 as indicated by current to fail-op coil and verified by transient actuator position errors. Switching shall occur within an actuator position error band 1% to 3% of full scale.</p>	<p>Actuator Slew time</p> <p>Actuator Slew time</p> <p>Maximum Actuator Position Error Including Sign</p>
φ 26	MFV Actuator Channel 2	<p>Initial Conditions: Emergency Shutdown Control Valve energized. Fail-op valve de-energized, fail-safe valve energized coil 2 only. Coil 1 fail-safe valve inhibited. Logic which prevents servo Channel 2 to 1 transfer inhibited. MFV closed.</p> <p>a. Cause transfer to Channel No. 2 servovalve operation</p>	<p>a. System transfers to Channel 2 with fail-op coil energized. Actuator position error remains less</p>	<p>Actuator Position Error</p>

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TABLE III- (Continued)

Failure Mode Identification No.	Failure Identification Name	Description of Test	Acceptable Performance Criteria	Failure Parameter Name
φ 26 (Cont.)	MFV Actuator Channel 2	<p>b. De-energize coil 2 of fail-safe valve then step position reference to close.</p> <p>c. Energize coil 2 of fail-safe valve</p> <p>d. Step position reference to 50% open.</p> <p>e. Verify operation of Channel No. 2 servo-valve self monitoring circuits for both plus and minus servo-valve spool position errors (See Note 5)</p>	<p>than 1% during process. Failure of Channel transfer will cause greater than 1% error.</p> <p>b. Valve remains open.</p> <p>c. Valve closes in 0.360 ± 0.060 sec</p> <p>d. Valve opens to 50% in 0.180 ± 0.040 sec</p> <p>e. Coil 2 of fail-safe valve de-energized to limit actuator excursion to $\pm 3.0\%$ of travel</p>	<p>Actuator Position Change</p> <p>Actuator Slew Time</p> <p>Actuator Slew Time</p> <p>Maximum Actuator Error Including Sign</p>
φ 27	Main Oxidizer Valve Actuator Channel 1	Same test procedure as for MFV Actuator Channel 1	<p>a. Same as MFV Channel 1</p> <p>b. Same as MFV Channel 1</p> <p>c. Valve closes in 0.460 ± 0.100 sec</p>	Same parameters as MFV Channel 1

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TABLE III (continued)

PART C (Continued)
 Failure Identification
 Mode Identification
 Failure Identification
 Name

Failure Parameter Name
 Acceptable Performance Criteria

Description of Test

φ 27 (Cont.) Main Oxidizer Valve Actuator Channel 1	d. Valve opens to 50% in 0.240 ± 0.060 sec e. Same as MFV Channel 1		Same parameters as MFV Channel 2
φ 28 Main Oxidizer Valve Actuator Channel 2	a. Same test procedure as for MFV Actuator Channel 2 b. Same as MFV Channel 2 c. Valve closes in 0.460 ± 0.100 sec d. Valve opens to 50% in 0.240 ± 0.060 sec e. Coil 2 of fail- safe valve de-energized to limit actuator excursion to $\pm 3.0\%$ of travel		Same parameters as MFV Channel 1
φ 29 Chamber Coolant Valve Actuator Channel 1	a. Same test procedure as for MFV Channel 1 b. Same as MFV Channel 1 c. Valve closes in 0.500 ± 0.080 sec d. Valve opens to 50% in 0.260 ± 0.040 sec		

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TABLE III (Continued)

Failure Mode Identification No.	Failure Identification Name	Description of Test	Acceptable Performance Criteria	Failure Parameter Name
φ 29 (Cont.)	Chamber Coolant Valve Actuator Channel 1	e. Same as MFV Channel 1	Same as MFV Channel 1	
φ 30	Chamber Coolant Valve Actuator Channel 2	a. Same test procedure as for MFV Channel 2	a. Same as MFV Channel 2	Same parameters as MFV Channel 2
		b. Same as MFV Channel 2	Same as MFV Channel 2	
		c. Valve closes in 0.500 ± 0.080 sec	Valve closes in 0.500 ± 0.080 sec	
		d. Valve opens to 50% in 0.260 ± 0.040 sec	Valve opens to 50% in 0.260 ± 0.040 sec	
		e. Coil 2 of fail-safe valve de-energized to limit actuator excursion to $\pm 3.0\%$ of travel	Coil 2 of fail-safe valve de-energized to limit actuator excursion to $\pm 3.0\%$ of travel	
φ 31	Fuel Preburner Oxidizer Valve Actuator Channel 1	a. Same test procedure as for MFV Channel 1	Same as MFV Channel 1	Same parameters as MFV Channel 1
		b. Same as MFV Channel 1	Same as MFV Channel 1	
		c. Valve closes in 0.500 ± 0.080 sec	Valve closes in 0.500 ± 0.080 sec	
		d. Valve opens to 50% in 0.260 ± 0.040 sec	Valve opens to 50% in 0.260 ± 0.040 sec	

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TABLE III
(Continued)

PART (Continued)

Failure Mode Identification No.	Failure Identification Name	Description of Test	Acceptable Performance Criteria	Failure Parameter Name
φ 31 (Cont.)	Fuel Preburner Oxidizer Valve Actuator Channel 1	e. Same as MFV Channel 1		
φ 32	Fuel Preburner Oxidizer Valve Actuator Channel 2	Same test procedure as for MFV Channel 2	a. Same as MFV Channel 2 b. Same as MFV Channel 2 c. Valve closes in 0.500 ± 0.080 sec d. Valve opens to 50% in 0.260 ± 0.040 sec e. Coil 2 of fail-safe valve de-energized to limit actuator excursion to + 3.0 percent of travel	Same parameters as MFV Channel 2
φ 33	Oxidizer Preburner Oxidizer Valve Actuator Channel 1	Same test procedure as for MFV Channel 1	a. Same as MFV Channel 1 b. Same as MFV Channel 1 c. Valve closes in 0.500 ± 0.080 sec d. Valve opens to 50% in 0.260 ± 0.040 sec	Same parameters as MFV Channel 1

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TABLE III- (Continued)

Failure Mode Identification No.	Failure Identification Name	Description of Test	Acceptable Performance Criteria	Failure Parameter Name
33 (Cont.)	Oxidizer Preburner Oxidizer Valve Actuator Channel 1	e. Same as MFV Channel 1		
34	Oxidizer Preburner Oxidizer Valve Actuator Channel 2	a. Same test procedure as for MFV Channel 2 b. Same as MFV Channel 2 c. Valve closes in 0.500 ± 0.030 sec d. Valve opens to 50% in 0.260 ± 0.040 sec e. Coil 2 of fail-safe valve de-energized to limit actuator excursion to $\pm 3.0\%$ of travel	Same parameters as MFV Channel 2	

PART D: PRESSURE SENSORS

All flight operation pressure sensors will be subjected to the same automatic checkout procedure. Checkout will be accomplished by shunt resistor switching of the sensor bridge circuit and readout of sensor output at ambient and simulated 80% of sensor full scale output. The sensor output will be provided to the vehicle as the failure parameter output. Acceptable pressure sensor performance criteria in terms of millivolt output for 10 ± 0.01 volt excitation are given below.

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TABLE III. (Continued)

φ PART D: (Continued) Acceptable Performance Criteria

Failure Mode Identification No.	Failure Identification Name	Ambient		80%	
		Min.	Max.	Min.	Max.
13	Oxidizer System Purge Press. Sensor	-0.77	1.63	23.23	25.63
14	Fuel System Purge Press. Sensor	-0.77	1.63	23.23	25.63
15	Fuel Liftoff Seal & Bleed Valve Control Press. Sensor	-0.77	1.63	23.23	25.63
16	Oxidizer Bleed Valve Control Press. Sensor	-0.77	1.63	23.23	25.63
φ 17	HPOT Intermediate Seal Purge Press. Sensor Channel 1	1.97	5.51	26.00	29.54
φ 18	HPOT Int. Seal Purge Press. Sensor Channel 2	1.97	5.51	26.00	29.54
43	LPFT Disch. Press. Sensor No. 1 Channel 1	-1.0	2.31	23.0	26.31
44	LPFT Disch. Press. Sensor No. 1 Channel 2	-1.0	2.31	23.0	26.31
45	LPFT Disch. Press. Sensor No. 2 Channel 1	-1.0	2.31	23.0	26.31
50	HPOT Turbine Seal Purge Press. Sensor	-0.77	1.63	23.23	25.63
58	Fuel Preburner Press. Sensor	-1.13	1.28	22.87	25.28
59	HPFT Discharge Press. Sensor	-1.14	1.26	22.86	25.26
65	LPOT Discharge Press. Sensor Channel 1	-0.46	1.94	23.54	25.94
66	LPOT Discharge Press. Sensor Channel 2	-0.46	1.94	23.54	25.94

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TABLE III (Continued)

PART D: (Continued)	Failure Mode Identification No.	Failure Identification Name	Acceptable Performance Criteria			
			Ambient		80%	
			Min.	Max.	Min.	Max.
70		HPOT Discharge Press. Sensor No. 1 Channel 1	-1.13	1.28	22.87	25.28
71		HPOT Discharge Press. Sensor No. 1 Channel 2	-1.13	1.28	22.87	25.28
72		HPOT Discharge Press. Sensor No. 2 Channel 1	-1.13	1.28	22.87	25.28
78		HPOT Boost Stage Discharge Press. Sensor	-1.15	1.26	22.85	25.26
82		Oxid. Preburner Chamber Press. Sensor	-1.13	1.28	22.87	25.28
88		Oxid. Tank Pressurant Press. Sensor Channel 1	-1.13	1.28	22.87	25.28
89		Oxid. Tank Pressurant Press. Sensor Channel 2	-1.13	1.28	22.87	25.28
90		Main Combustion Chamber Fuel Injector Press. Sensor	-1.19	1.21	22.81	25.21
91		Main Combustion Chamber Press. Sensor No. 1 Channel 1	-1.07	1.33	22.93	25.33
92		Main Combustion Chamber Press. Sensor No. 1 Channel 2	-1.07	1.33	22.93	25.33
93		Main Combustion Chamber Press. Sensor No. 2 Channel 1	-1.07	1.33	22.93	25.33
95		Main Combustion Chamber Coolant Press. Sensor	-1.11	1.29	22.89	25.29

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TABLE III (Continued)

PART D: (Continued)

Acceptable Performance Criteria

Failure Mode Identification No.	Failure Identification Name	Ambient	80%
		Min.	Max.

97	Hydraulic System Press. Sensor Channel 1	See Note 2	
98	Hydraulic System Press. Sensor Channel 2	See Note 2	
101	Controller Int. Press. Sensor Channel 1	TBD See Note 5	
102	Controller Int. Press. Sensor Channel 2	TBD See Note 5	

PART E: TEMPERATURE SENSORS

All temperature sensors will be subjected to the same automatic checkout procedures. Checkout will be accomplished by insertion of checkout shunt resistors in the sensor bridge circuits and readout of sensor output with and without the shunt. The sensor output will be provided to the vehicle as the failure parameter output. Acceptable sensor performance criteria in terms of millivolt output for 10 \pm 0.01 volts excitation are given below.

Acceptable Performance Criteria

Failure Mode Identification No.	Failure Identification Name	Without Checkout Shunt	With Checkout Shunt
		Min. Output	Max. Output

MEDIUM AND HIGH TEMPERATURE SENSORS

56	HPFT Turbine Discharge Temperature Sensor No. 1	TBD See Note 3	
57	HPFT Turbine Discharge Temperature Sensor No. 2		
80	HPOT Turbine Discharge Temperature Sensor No. 1		

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TABLE III (Continued)

PART E: (Continued)

Acceptable Performance Criteria

Failure Mode Identification No.	Failure Identification Name	Without Checkout Shunt	With Checkout Shunt
		Min. Output	Max. Output

MEDIUM AND HIGH TEMPERATURE SENSOR (Cont'd)

81	HPOT Turbine Discharge Temperature Sensor No. 2	← ——— TBD See Note 3 ——— →	
94	Main Combustion Chamber Coolant Temperature Sensor		
99	Controller Internal Temperature Sensor Channel 1		
100	Controller Internal Temperature Sensor Channel 2		

CRYOGENIC TEMPERATURE SENSORS

46	LPFT Discharge Temperature Sensor No. 1 Channel 1		
47	LPFT Discharge Temperature Sensor No. 1 Channel 2		
48	LPFT Discharge Temperature Sensor No. 2 Channel 1		
73	HPOT Discharge Temperature Sensor No. 1 Channel 1		
74	HPOT Discharge Temperature Sensor No. 1 Channel 2		
75	HPOT Discharge Temperature Sensor No. 2 Channel 1		

PART F: VIBRATION SENSORS

All vibration sensors will be subjected to the same checkout procedure. Checkout will be accomplished by capacitive coupling excitation of each sensor at 2000 Hz plus or minus 100 Hz and at a simulated voltage amplitude equivalent to the vibration level specified below. Output of the sensor as processed by the controller electronics shall be compared with preselected limits. Processed sensor output shall be

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TABLE III. (Continued)

PART (Continued)

supplied to the vehicle as the failure parameter. Sensors, corresponding test levels and performance criteria are listed below.

Failure Mode Identification No.	Failure Identification Name	Description of Test Vibration Level	Acceptable Performance	
			Input g RMS	Output Deviation from Input
51	LPFT Radial Vibration	150		±15
63	HPFT Radial Vibration	150		±15
64	Fuel Preburner Longitudinal Vibration	500		±50
69	LPOT Radial Vibration	150		±15
79	HPOT Radial Vibration	150		±15
83	Oxidizer Preburner Longitudinal Vibration	500		±50
96	Main Combustion Chamber Longitudinal Vibration	500		±50

PART G: SPEED AND FLOWRATE SENSORS

All speed and flow sensors will be subjected to the same checkout procedure. Checkout will be accomplished by exciting one of the sensor windings with frequency signals at TBD Hz for the speed sensors and TBD Hz for the flow sensors. Both outputs of each sensor as monitored and converted to an equivalent of the sensor excitation frequency by the controller electronics shall be compared with the excitation frequency. For acceptable performance maximum frequency difference shall be TBD Hz for the speed sensors and TBD Hz

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TABLE III: (Continued)

TABLE III (Continued)			
PART G: (Continued)			
for the flow sensors. The failure parameter supplied to the vehicle shall be the frequency difference. Sensors to which these criteria apply are given below:			
Speed Sensors			
Failure Mode Identification No.		Failure Identification Name	Failure Mode Identification No.
49	LPFT Shaft Speed Sensor		52
61	HPFT Shaft Speed Sensor Channel 1		53
62	HPFT Shaft Speed Sensor Channel 2		54
67	LPOT Shaft Speed Sensor		84
76	HPOT Shaft Speed Channel 1		85
77	HPOT Shaft Speed Channel 2		86
PART H: IGNITER TESTS			
All igniters will be subjected to the same automatic check-out procedure. Igniters will be energized simultaneously and spark voltage level and spark rate verified for each igniter. When energized, the spark voltage and spark rate for each spark igniter shall be verified by the controller built-in-test equipment which provides a signal indicative of the igniter operational status. Igniter voltage and rate requirements are defined in FC1007. Igniters to which these criteria apply and their corresponding Failure Mode Identification Numbers are given below.			

PART H: IGNITER TESTS

All igniters will be subjected to the same automatic checkout procedure. Igniters will be energized simultaneously and spark voltage level and spark rate verified for each igniter. When energized, the spark voltage and spark rate for each spark igniter shall be verified by the controller built-in-test equipment which provides a signal indicative of the igniter operational status. Igniter voltage and rate requirements are defined in RC1007. Igniters to which these criteria apply and their corresponding Failure Mode Identification Numbers are given below.

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TABLE III (Concluded)

PART H (Continued)

Failure Mode
Identification

Failure
Identification
Name

No.

- | | |
|----|---------------------------------------|
| 19 | Fuel Preburner Igniter No. 1 |
| 20 | Fuel Preburner Igniter No. 2 |
| 21 | Oxidizer Preburner Igniter No. 1 |
| 22 | Oxidizer Preburner Igniter No. 2 |
| 23 | Main Combustion Chamber Igniter No. 1 |
| 24 | Main Combustion Chamber Igniter No. 2 |

NOTES:

- φ 1. Except where noted all Checkout phase tests will be performed with 13 to 15 psia pressure at the sense point, 430 R to 590 R ambient temperature with no propellants in the system, hydraulic pressure 3000 (plus 500, minus 300) psia, and 600 (plus or minus 60) psia GN2, and 750 (plus or minus 50) psia He pneumatic supply pressure at the vehicle interface.
2. Checkout will consist of verification that each scaled hydraulic sensor output is equal to 3000 (plus 560, minus 360) psia and that both scaled sensor outputs agree within 85 psia.
3. Maximum and minimum outputs for temperature sensors during checkout shall be supplied by the controller supplier when the bridge circuits and checkout shunt resistors have been selected.
- φ 4. Individual tests within a series of tests associated with a failure mode identification number shall be identified by a test number. The controller response for a failure to satisfy a test specified in this table shall be as defined in Table III.
5. Acceptable performance criteria to be determined by Controls Subcontractor.
6. Performance of the Automatic Checkout sequence shall not require any sequencing of vehicle functions while Automatic Checkout is in progress.
- φ 7. Verification of pressure level with a non-redundant sensor shall be performed by comparing the sensor output to a fixed voltage equivalent to the pressure level specified.
- φ 8. Unless otherwise noted, all solenoid and torque motor coils shall initially be de-energized.

TABLE IV
VEHICLE TO ENGINE COMMANDS

<p>X - Phase when command is accepted. ⊗ - Phase when command is normally required by engine.</p>					
Command		Function			
PURGE SEQUENCE NO. 1		INITIATES 1) START PREPARATION PHASE 2) GN ₂ PURGE 3) HPOT INTERMEDIATE SEAL PURGE			
PURGE SEQUENCE NO. 2		INITIATES FUEL SYSTEM PURGE OPENS BLEED VALVES AND APPLIES PUMP LIFTOFF SEALS TERMINATES 1) FUEL SYSTEM PURGE 2) HPOT INTERMEDIATE SEAL PURGE			
PURGE SEQUENCE NO. 3		INITIATES FUEL SYSTEM PURGE DURING PROPELLANT RECIRCULATION INITIATES 1) START PHASE 2) HPOT INTERMEDIATE SEAL PURGE TERMINATES 1) GN ₂ PURGE 2) FUEL SYSTEM PURGE			
PURGE SEQUENCE NO. 4		CLOSERS BLEED VALVES AND RELEASES PUMP LIFTOFF SEALS			
START	X	INITIATES ENGINE SHUTDOWN PHASE TERMINATES HPOT INTERMEDIATE SEAL PURGE			
SHUTDOWN	X				
Mainstage	⊗				
Shutdown					
Post-Shutdown					
Start Preparation	X				
Start	X				
Checkout	⊗				

TABLE IV
VEHICLE TO ENGINE COMMANDS
(Cont'd)

<p>X - Phase when command is accepted. (X) - Phase when command is normally required by engine.</p>					
Command	Function				
THRUST LEVEL					COMMANDS ENGINE THRUST LEVEL
MIXTURE RATIO					COMMANDS ENGINE MIXTURE RATIO
LIMIT CONTROL INHIBIT					INHIBITS TEMPERATURE LIMIT CONTROL AND CONTROLLER INITIATED ENGINE SHUTDOWN
LIMIT CONTROL ENABLE					ENABLES TEMPERATURE LIMIT CONTROL AND CONTROLLER INITIATED ENGINE SHUTDOWN
ABORT TURNAROUND PURGE SEQUENCE NO. 1					INITIATES 1) ABORT TURNAROUND MODE 2) GN ₂ PURGE 3) FUEL SYSTEM PURGE 4) IPQT INTERMEDIATE SEAL PURGE
ABORT TURNAROUND PURGE SEQUENCE NO. 2					OPENS BLEED VALVES AND APPLIES PUMP LIFTOFF SEALS
OXIDIZER DUMP					TBD
FUEL DUMP					TBD
TERMINATE PROPELLANT DUMP					TBD
MAIN FUEL VALVE					} CONTROLS VALVES DURING ENGINE COMPONENT CHECKOUT
MAIN OXIDIZER VALVE					
FUEL PREBURNER OXIDIZER VALVE					
OXIDIZER PREBURNER					
OXIDIZER VALVE					
COOLANT CONTROL VALVE					
Start Preparation	X				
Start	X				
Mainstage	X				
Shutdown					
Post-Shutdown					

TABLE IV
VEHICLE TO ENGINE COMMANDS
(Cont'd)

					X - Phase when command is accepted. ⊗ - Phase when command is normally required by engine.	
Checkout	Start Preparation	Start	Mainstage	Shutdown	Post-Shutdown	Command
X	X				X	CONTROLLER RESET
X	X					GN ₂ SYSTEM PURGE CONTROL VALVE
X	X					FUEL SYSTEM PURGE CONTROL VALVE
X	X					LIFTOFF SEAL AND BLEED VALVE
X	X					CONTROL VALVE
X	X					HPOT INTERMEDIATE SEAL PURGE
X	X					CONTROL VALVE
X	X					EMERGENCY SHUTDOWN CONTROL VALVE
X	X					SENSOR CHECKOUT
X	X					SPARK IGNITER CHECKOUT
X	X					REDUNDANCY VERIFICATION COMMANDS (TBD)
X	X					LOAD SOFTWARE, COMPUTER 1
X	X					LOAD SOFTWARE, COMPUTER 2
X	X					TERMINATE SOFTWARE LOAD
X	X					SUM CHECK
						RESETS CONTROLLER TO INITIAL CONDITION OF CHECKOUT PHASE - STANDBY OPERATING SELFTEST MODE INITIATES CHECKOUT OF PNEUMATIC VALVES DURING COMPONENT CHECKOUT INITIATES CHECKOUT OF SENSORS INITIATES CHECKOUT OF SPARK IGNITERS VERIFIES ENGINE REDUNDANCY INITIATES MEMORY LOADING THROUGH THE VEEI. INITIATES READ/WRITE AND SUM CHECK OF MEMORY.

TABLE IV
VEHICLE TO ENGINE COMMANDS
(cont'd)

Checkout	Start Preparation	Start	Mainstage	Shutdown	Post-Shutdown	Command	Function
X						<p>X - Phase when command is accepted. (X) - Phase when command is normally required by engine.</p>	
X						<p>MEMORY READOUT, COMPUTER 1 MEMORY READOUT, COMPUTER 2 SIMULATE OUT-OF-LIMITS PREFLIGHT CALIBRATION FRT CHANNEL 1 FRT CHANNEL 2 OPEN MAIN FUEL VALVE OPEN MAIN OXIDIZER VALVE OPEN FUEL PREBURNER OXIDIZER VALVE OPEN OXIDIZER PREBURNER OXIDIZER VALVE OPEN COOLANT CONTROL VALVE FRT EXIT RESUME</p>	<p>} INITIATES READOUT OF MEMORY THROUGH THE VEEL. SIMULATES A HIGH PREBURNER TEMPERATURE CONDITION DURING FRT. INITIATES CALIBRATION OF PERFORMANCE CONTROL PRESSURE SENSORS * IMPLEMENTS FRT SEQUENCE IMPLEMENTS FRT SEQUENCE } POSITIONS PROPELLANT VALVES FOR ENGINE LEAK CHECK. VALVES ARE CLOSED VIA CONTROLLER RESET.</p>
X							*COMMANDS MAY BE USED TO CHANGE CONTROLLER CHANNELS DURING ANY PHASE AFTER FRT HAS BEEN INITIATED.

TABLE IV
VEHICLE TO ENGINE COMMANDS
(cont'd)

Checkout	Start Preparation	Start	Mainstage	Shutdown	Post-Shutdown	X - Phase when command is accepted. ⊗ - Phase when command is normally required by engine.	
						Command	Function
X						ENERGIZE (OPEN) FUEL SYSTEM PURGE CONTROL VALVE	POSITIONS PNEUMATIC VALVES FOR ENGINE LEAK CHECK. VALVES ARE DE-ENERGIZED VIA CONTROLLER RESET.
X						ENERGIZE (OPEN) GN ₂ SYSTEM PURGE CONTROL VALVE	
X						ENERGIZE (CLOSE) EMERGENCY SHUTDOWN CONTROL VALVE	
X						ENERGIZE (OPEN) HPOT INTERMEDIATE SEAL PURGE CONTROL VALVE	
X						ENERGIZE (OPEN) LIFTOFF SEAL AND BLEED VALVE CONTROL VALVE	

TABLE V

STATUS/RECORDER DATA TRANSMITTED TO VEHICLE

DATA (2)	DATA WORD	SCALED RANGE	PRECISION OF DATA (3)	DATA INTERVAL - MS
IDENTIFICATION WORD NO. 1	1	-	-	40
IDENTIFICATION WORD NO. 2	2	-	-	40
ENGINE STATUS	3	-	-	40
MIXTURE RATIO	4	0-8	±1%	40
THRUST	5	0-520K	±6K LBS	40
FAILURE IDENTIFICATION (11)	6	-	-	40
TEST NO. OF DATA WORD NO. 6 (11)	7	-	-	40
PARAMETER VALUE OF DATA WORD NO. 6	8	-	-	40
MAIN COMBUSTION CHAMBER PRESSURE	9-12	0-3500 PSI	±2% F.S.	10
MAIN FUEL VALVE ACTUATOR POSITION	13-14	0-100%	±1% F.S.	20
MAIN OXIDIZER VALVE ACTUATOR POSITION	15-16	0-100%	±1% F.S.	20
FUEL BLEED VALVE POSITION	17	0-100% (7)	±1% F.S.	40
OXIDIZER BLEED VALVE POSITION	18	0-100% (7)	±1% F.S.	40
HPOT DISCHARGE PRESSURE	19-22	0-9500 PSI (7)	±2% F.S.	10
HPOT DISCHARGE PRESSURE	23-26	0-7000 PSI	±2% F.S.	10
FUEL FLOWRATE	27-30	0-18000 GPM	±1% F.S. (4)	10
OXIDIZER FLOWRATE	31-34	0-7000 GPM	±1% F.S. (4)	10
HYDRAULIC SYSTEM PRESSURE	35	0-4000 PSI	±2% F.S.	40
LPFT DISCHARGE PRESSURE	36-39	0-300 PSI	±2% F.S.	10
LPFT DISCHARGE TEMPERATURE	40	30 to 55 R	±2%	40
LPFT SHAFT SPEED	41	0-20000 RPM (7)	±1% F.S. (5)	40
LPFT RADIAL VIBRATION	42	0-300g RMS (7)	±5% F.S.	40
HPFT SHAFT SPEED	43	0-45000 RPM	±1% F.S. (5)	40
HPFT RADIAL VIBRATION	44	0-300g RMS (7)	±5% F.S.	40
HPFT TURBINE DISCHARGE TEMPERATURE	45	460-2760R	±2%	40
FUEL PREBURNER CHAMBER PRESSURE	46-47	0-7000 PSI (7)	±2%	20
LPOT DISCHARGE PRESSURE	48-51	0-600 PSI	±2% F.S. (5)	10
LPOT SHAFT SPEED	52	0-6000 RPM (7)	±1% F.S. (5)	40
LPOT RADIAL VIBRATION	53	0-300g RMS (7)	±5% F.S.	40
HPOT DISCHARGE TEMPERATURE	54	160 TO 210 R	±2%	40
HPOT BOOST STAGE DISCHARGE PRESSURE	55-56	0-9500 PSI (7)	±2% F.S. (5)	20
HPOT SHAFT SPEED	57	0-35000 RPM	±1% F.S.	40
HPOT RADIAL VIBRATION	58	0-500g RMS (7)	±5% F.S.	40
HPOT TURBINE DISCHARGE TEMPERATURE	59	460-2760R	±2%	40

TABLE V
(CONTINUED)

DATA (2)	DATA WORD	SCALED RANGE	PRECISION OF DATA (3)	DATA INTERVAL - MS
OXIDIZER PREBURNER CHAMBER PRESSURE	60-61	0-7000 PSI (7)	±2% F.S.	20
MCC FUEL INJECTOR PRESSURE	62	0-4500 PSI (7)	±2% F.S.	40
MCC COOLANT TEMPERATURE	63	37 TO 1160 R (7)	±2%	40
OXIDIZER TANK PRESSURANT PRESSURE	64-65	0-7000 PSI	±2% F.S.	20
MCC COOLANT PRESSURE	66	0-7000 PSI (7)	±2% F.S.	40
MCC COOLANT VALVE ACTUATOR POSITION	67	0-100%	±1% F.S.	40
CPV ACTUATOR POSITION	68-69	0-100%	±1% F.S.	20
FPV ACTUATOR POSITION	70-71	0-100%	±1% F.S.	20
OXIDIZER SYSTEM PURGE PRESSURE	72	0-1000 PSI (7)	±2% F.S.	40
FUEL SYSTEM PURGE PRESSURE	73	0-1000 PSI (7)	±2% F.S.	40
HPOT TURBINE SEAL PURGE PRESSURE	74	0-1000 PSI (7)	±2% F.S.	40
HPOT INTERMEDIATE SEAL PURGE PRESSURE	75	0-100 PSI	±2% F.S.	40
TIME REFERENCE	76	-	-	40 (1)
FUEL PREBURNER LONGITUDINAL VIBRATION	77	0-1000g RMS (7)	±5% F.S. (9)	40
OXIDIZER PREBURNER LONGITUDINAL VIBRATION	78	0-1000g RMS (7)	±5% F.S. (9)	40
MCC LONGITUDINAL VIBRATION	79	0-1000g RMS (7)	±5% F.S. (9)	40
CONTROLLER INTERNAL PRESSURE	80	0-50 PSI	±2% F.S.	40
CONTROLLER INTERNAL TEMPERATURE	81	140 to 760 R	±2%	40
CONTROLLER BUS NO. 1 VOLTAGE	82	0-250 VAC L-L	±5% F.S.	40
CONTROLLER BUS NO. 2 VOLTAGE	83	0-250 VAC L-L	±5% F.S.	40
VEHICLE COMMANDS	84-89	-	-	40
OXIDIZER BLEED VALVE CONTROL PRESSURE		0-1000 PSI	±2% F.S.	40
FUEL LIFT-OFF SEAL AND BLEED VALVE CONTROL PRESSURE		0-1000 PSI	±2% F.S.	40

NOTES:

- (1) Updated every 20 milliseconds.
- (2) Data shall be transmitted at a rate of 25 times per second.
- (3) Precision of thrust and mixture ratio is a firm requirement. Precision stated for other data are desired values. Final precision values are TBD.
- (4) Useable range of scaled flow data shall extend from 3% of full scale to 100% of full scale.
- (5) Useable range of scaled speed data shall extend from 2.5% of full scale to 100% of full scale.
- (6) Word 84 contains first command received in a 40 millisecond period.

TABLE V
(CONTINUED)

NOTES:

- (7) Data from non-redundant sensors will not be scaled by the controller software before transmission on the status/recorder channels.
- (8) Data word order for the first 35 words is as shown. Data word order for the remaining words is not necessarily the order of transmission.
- (9) Data from longitudinal sensor will be transmitted on a rotational basis for each of the frequency bands. A unique identifying data constant shall be inserted between each sensor data block.

(10) Mnemonics used:

HPPT = High Pressure Fuel Turbopump
 HPOT = High Pressure Oxidizer Turbopump
 LPPT = Low Pressure Fuel Turbopump
 LPOT = Low Pressure Oxidizer Turbopump
 MCC = Main Combustion Chamber
 OPOV = Oxidizer Preburner Oxidizer Valve
 FPOV = Fuel Preburner Oxidizer Valve

(11) Failure Identification Table: TBD

TABLE VI

STATUS/RECORDER DATA TRANSMITTED TO VEHICLE

DATA (2)	DATA WORD	SCALED RANGE	PRECISION OF DATA (3)	DATA INTERVAL - MS
IDENTIFICATION WORD NO. 1	1	-	-	40
IDENTIFICATION WORD NO. 2	2	-	-	40
ENGINE STATUS	3	-	-	40
MIXTURE RATIO	4	0-8	±1%	40
THRUST	5	0-520K	±6K LBS	40
FAILURE IDENTIFICATION (11)	6	-	-	40
TEST NO. OF DATA WORD NO. 6 (11)	7	-	-	40
PARAMETER VALUE OF DATA WORD NO. 6	8	-	-	40
MAIN-COMBUSTION CHAMBER PRESSURE	9-12	0-3500 PSI	±2% F.S.	10
MAIN FUEL VALVE ACTUATOR POSITION	13-14	0-100%	±1% F.S.	20
MAIN OXIDIZER VALVE ACTUATOR POSITION	15-16	0-100%	±1% F.S.	20
FUEL BLEED VALVE POSITION	17	0-100% (7)	±1% F.S.	40
OXIDIZER BLEED VALVE POSITION	18	0-100% (7)	±1% F.S.	40
HPFT DISCHARGE PRESSURE	19-22	0-9500 PSI (7)	±2% F.S.	10
HPOT DISCHARGE PRESSURE	23-26	0-7000 PSI	±2% F.S.	10
FUEL FLOWRATE	27-30	0-18000 GPM	±1% F.S. (4)	10
OXIDIZER FLOWRATE	31-34	0-7000 GPM	±1% F.S. (4)	10
HYDRAULIC SYSTEM PRESSURE	35	0-4000 PSI	±2% F.S.	40
LPFT DISCHARGE PRESSURE	36-39	0-300 PSI	±2% F.S.	10
LPFT DISCHARGE TEMPERATURE	40	30 to 55 R	±2%	40
LPFT SHAFT SPEED	41	0-2000 RPM (7)	±1% F.S. (5)	40
LPFT RADIAL VIBRATION	42	0-300g RMS (7)	±5% F.S.	40
HPFT SHAFT SPEED	43	0-4000 RPM	±1% F.S.	40
HPFT RADIAL VIBRATION	44	0-300g RMS (7)	±5% F.S.	40
HPFT TURBINE DISCHARGE TEMPERATURE	45	460-2760 R	±2%	40
FUEL PREBURNER CHAMBER PRESSURE	46-47	0-7000 PSI	±2%	20
LPOT DISCHARGE PRESSURE	48-51	0-600 PSI	±2% F.S.	10
LPOT SHAFT SPEED	52	0-5000 RPM (7)	±1% F.S. (5)	40
LPOT RADIAL VIBRATION	53	0-300g RMS (7)	±5% F.S.	40
HPOT DISCHARGE TEMPERATURE	54	160 to 210 R	±2%	40
HPOT BOOST STAGE DISCHARGE PRESSURE	55-56	0-5000 PSI (7)	±2% F.S.	20
HPOT SHAFT SPEED	57	0-3000 RPM	±1% F.S. (5)	40
HPOT RADIAL VIBRATION	58	0-300g RMS (7)	±5% F.S.	40
HPOT TURBINE DISCHARGE TEMPERATURE	59	400-2760 R	±2%	40
OXIDIZER PREBURNER CHAMBER PRESSURE	60-61	0-7000 PSI (7)	±2% F.S.	20
MCC FUEL INJECTOR PRESSURE	62	0-4500 PSI (7)	±2% F.S.	40

TABLE VI (CONTD)

STATUS/RECORDER DATA TRANSMITTED TO VEHICLE

DATA(2)	DATA WORD	SCALED RANGE	PRECISION OF DATA(3)	DATA INTERVAL - MS
MCC COOLANT TEMPERATURE	63	37 to 1160 R(7)	±2%	40
OXIDIZER TANK PRESSURANT PRESSURE	64-65	0-7000 PSI	±2% F.S.	20
MCC COOLANT PRESSURE	66	0-7000 PSI(7)	±2% F.S.	40
MCC COOLANT VALVE ACTUATOR POSITION	67	0-100%	±1% F.S.	40
OPOV ACTUATOR POSITION	68-69	0-100%	±1% F.S.	20
FPOV ACTUATOR POSITION	70-71	0-100%	±1% F.S.	20
OXIDIZER SYSTEM PURGE PRESSURE	72	0-1000 PSI(7)	±2% F.S.	40
FUEL SYSTEM PURGE PRESSURE	73	0-1000 PSI(7)	±2% F.S.	40
HPOT TURBINE SEAL PURGE PRESSURE	74	0-1000 PSI(7)	±2% F.S.	40
HPOT INTERMEDIATE SEAL PURGE PRESSURE	75	0-100 PSI	±2% F.S.	40
OXIDIZER BLEED VALVE CONTROL PRESSURE	76	0-1000 PSI(7)	±2% F.S.	40
FUEL LIFTOFF SEAL AND BLEED VALVE CONTROL PRESSURE	77	0-1000 PSI(7)	±2% F.S.	40
TIME REFERENCE	78	-	-	40 (1)
FUEL PREBURNER LONGITUDINAL VIBRATION	79	0-1000g RMS(7)	±5% F.S.(9)	40
OXIDIZER PREBURNER LONGITUDINAL VIBRATION	80	0-1000g RMS(7)	±5% F.S.(9)	40
MCC LONGITUDINAL VIBRATION	81	0-1000g RMS(7)	±5% F.S.(9)	40
CONTROLLER INTERNAL PRESSURE	82	0-50 PSI	±2% F.S.	40
CONTROLLER INTERNAL TEMPERATURE	83	140 to 760 R	±2%	40
CONTROLLER BUS NO. 1 VOLTAGE	84	0-250 VAC L-L	±5% F.S.	40
CONTROLLER BUS NO. 2 VOLTAGE	85	0-250 VAC L-L	±5% F.S.	40
VEHICLE COMMANDS	86-91	-	-	40

NOTES:

(1) Updated every 20 milliseconds.

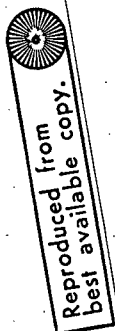
(2) Data shall be transmitted at a rate of 25 times per second.

(3) Precision of thrust and mixture ratio is a firm requirement. Precisions stated for other data are desired values. Final precision values are TBD.

(4) Usable range of scaled flow data shall extend from 3% of full scale to 100% of full scale.

TABLE VI - (CONTD)

STATUS/RECORDER DATA TRANSMITTED TO VEHICLE



- (5) Useable range of scaled speed data shall extend from 2.5% of full scale to 100% of full scale.
- (6) Word 86 contains first command received in a 40 millisecond period.
- (7) Data from non-redundant sensors will not be scaled by the controller software before transmission on the status/recorder channels.
- (8) Data word order for the first 35 words is as shown. Data word order for the remaining words is not necessarily the order of transmission.
- (9) Data from longitudinal sensor will be transmitted on a rotational basis for each of the frequency bands. A unique identifying data constant shall be inserted between each sensor data block.

(10) Mnemonics used:

HPFT - High Pressure Fuel Turbopump
 HPOT = High Pressure Oxidizer Turbopump
 LPFT = Low Pressure Fuel Turbopump
 LPOT = Low Pressure Oxidizer Turbopump
 MCC = Main Combustion Chamber
 OPOV = Oxidizer Preburner Oxidizer Valve
 FPOV = Fuel Preburner Oxidizer Valve

(11) Failure Identification (Description contained in RC1010).

TABLE VII
VEHICLE/ENGINE COMMAND CODE FORMAT

<u>TOTAL CODE</u>			<u>BCH</u>	<u>ACTUAL CODE</u>	<u>COMMAND</u>
1 000 001 100 000 000	000	000	---	101400	PURGE SEQUENCE NO. 1
1 000 010 000 000 000	000	000	---	102000	PURGE SEQUENCE NO. 2
1 000 010 100 000 000	000	000	---	102400	PURGE SEQUENCE NO. 3
1 000 011 000 000 000	000	000	---	103000	PURGE SEQUENCE NO. 4
1 000 011 100 000 000	000	000	---	103400	START
1 000 011 100 000 000	000	000	---	101000	SHUTDOWN
1 000 001 000 000 000	000	000	---	040000	THRUST LEVEL (1)
0 100 000 000 000 000	000	000	---	to	
0 111 101 100 000 000	000	000	---	075400	MIXTURE RATIO (2)
0 000 000 100 000 000	000	000	---	000400	
0 001 010 100 000 000	000	000	---	to	
1 000 000 000 000 000	000	000	---	012400	LIMIT CONTROL INHIBIT
1 000 000 100 000 000	000	000	---	100000	LIMIT CONTROL ENABLE
1 000 000 100 000 000	000	000	---	100400	ABORT TURNAROUND PURGE SEQUENCE NO. 1
1 000 101 100 000 000	000	000	---	105400	ABORT TURNAROUND PURGE SEQUENCE NO. 2
1 000 110 000 000 000	000	000	---	106000	OXIDIZER DUMP
1 000 100 000 000 000	000	000	---	104000	FUEL DUMP
1 000 100 100 000 000	000	000	---	101400	TERMINATE PROPELLANT DUMP
1 000 101 000 000 000	000	000	---	105000	MAIN FUEL VALVE
1 000 111 000 000 000	000	000	---	107000	MAIN OXIDIZER VALVE
1 000 111 100 000 000	000	000	---	107400	FUEL PREBURNER OXIDIZER VALVE
1 001 000 000 000 000	000	000	---	110000	OXIDIZER PREBURNER OXIDIZER VALVE
1 001 000 100 000 000	000	000	---	110400	COOLANT CONTROL VALVE
1 001 001 000 000 000	000	000	---	111000	CONTROLLER RESET
1 000 110 100 000 000	000	000	---	106400	FRT CHANNEL 1
1 001 101 000 000 000	000	000	---	115000	FRT CHANNEL 2
1 001 101 100 000 000	000	000	---	115400	GN2 SYSTEM PURGE CONTROL VALVE
1 001 001 100 000 000	000	000	---	111400	FUEL SYSTEM PURGE CONTROL VALVE
1 001 010 000 000 000	000	000	---	112000	LIFTOFF SEAL AND BLEED VALVE CONTROL
1 001 010 100 000 000	000	000	---	112400	VALVE
1 001 011 000 000 000	000	000	---	113000	HPOT INTERMEDIATE SEAL PURGE CONTROL
1 001 011 100 000 000	000	000	---	113400	VALVE
1 001 011 100 000 000	000	000	---	113400	EMERGENCY SHUTDOWN CONTROL VALVE

TABLE VII-1 (continued)

VEHICLE/ENGINE COMMAND CODE FORMAT


 Reproduced from
best available copy.
TOTAL CODEACTUAL
CODECOMMANDCOMMANDBCH

1 001 100 000 000 000	---	---	---	---	SENSOR CHECKOUT
1 001 100 100 000 000					SPACE PREBURNER CHECKOUT
1 010 100 100 000 000					
1 111 000 000 000 000					TERMINAL SOFTWARE LOAD
1 001 111 000 000 000					SUM CHECK
1 010 000 100 000 000					MEMORY READOUT, COMPUTER 1
1 010 001 000 000 000					MEMORY READOUT, COMPUTER 2
1 001 110 100 000 000					SIMULATE OUT-OF-LIMITS
1 010 010 000 000 000					OPEN MAIN FUEL VALVE
1 010 010 100 000 000					OPEN MAIN OXIDIZER VALVE
1 010 011 000 000 000					OPEN OXIDIZER PREBURNER OXIDIZER VALVE
1 010 011 100 000 000					
1 010 011 100 000 000					OPEN FUEL PREBURNER OXIDIZER VALVE
1 010 100 000 000 000					OPEN COOLANT CONTROL VALVE
1 010 100 100 000 000					ENERGIZE (OPEN) FUEL SYSTEM PURGE CONTROL VALVE
1 010 101 000 000 000					ENERGIZE (OPEN) GN2 SYSTEM PURGE CONTROL VALVE
1 010 101 100 000 000					ENERGIZE (CLOSE) EMERGENCY SHUTDOWN CONTROL VALVE
1 010 110 000 000 000					ENERGIZE (OPEN) HPOT INTERMEDIATE SEAL PURGE CONTROL VALVE
1 010 110 100 000 000					ENERGIZE (OPEN) LIFTOFF SEAL AND BLEED VALVE CONTROL VALVE
					REDUNDANCY VERIFICATION COMMANDS
					TBD

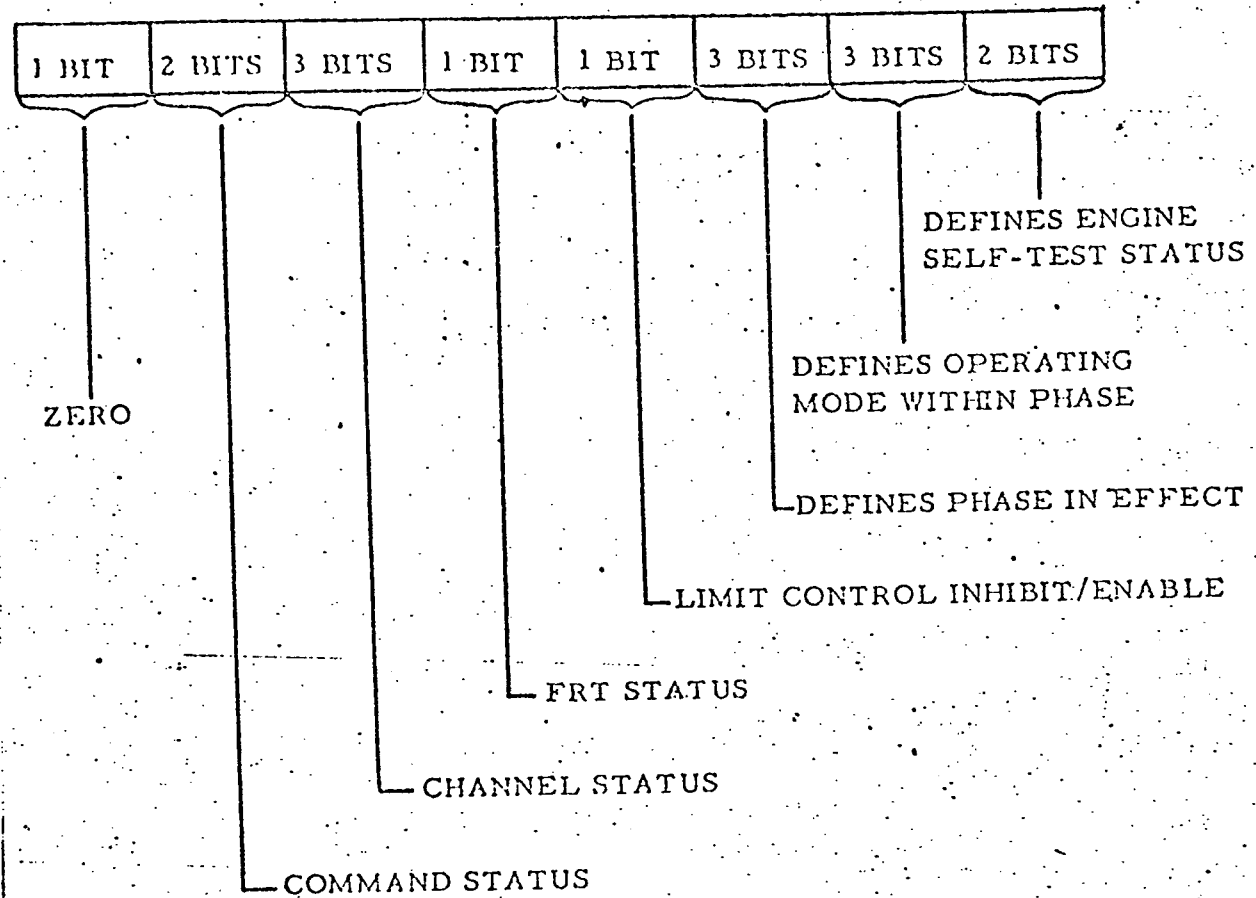
NOTES:

- (1) COMMANDS THRUST LEVEL (PER 400g CHANGE IN COMMAND) BETWEEN 50 AND 109 PERCENT
NPL IN ONE PERCENT INCREMENTS.
- (2) COMMANDS MIXTURE RATIO (PER 400g CHANGE IN COMMAND) BETWEEN 5.5 AND 6.5 IN
0.05 UNIT INCREMENTS.

13M15000F

TABLE VIII
ENGINE STATUS WORD

WORD FORMAT



NOTE: WORD LENGTH EQUALS 16 BITS EXCLUDING PARITY BIT

GROUP CODE

COMMAND STATUS: (2 BITS)

<u>BIT CODE</u>	<u>COMMAND STATUS</u>
00	NO COMMAND SINCE LAST STATUS/RECORDER CHANNEL TRANSMISSION
01	COMMAND REJECTED (NOT VALIDATED BY BCH OR VOTING)
10	COMMAND REJECTED (INCOMPATIBLE WITH CURRENT OPERATING MODE OR NOT IN TABLE OF COMMANDS)
11	COMMAND ACCEPTED

13M15000F

TABLE VIII (Continued)
ENGINE STATUS WORD

CHANNEL STATUS: (3 BITS)

<u>BIT CODE</u>	<u>CHANNEL STATUS</u>
000	ALL CHANNELS OK
001	MESSAGE ERROR, CHANNEL 1
010	MESSAGE ERROR, CHANNEL 2
011	MESSAGE ERROR, CHANNELS 1 & 2
100	MESSAGE ERROR, CHANNEL 3
101	MESSAGE ERROR, CHANNELS 1 & 3
110	MESSAGE ERROR, CHANNELS 2 & 3
111	MESSAGE ERROR, CHANNELS 1, 2, & 3

FRT STATUS: (1 BIT)

<u>BIT CODE</u>	<u>FRT STATUS</u>
0	NORMAL OPERATION
1	FRT

LIMIT CONTROL INHIBIT/ENABLE: (1 BIT)

<u>BIT CODE</u>	<u>LIMIT CONTROL</u>
0	INHIBIT
1	ENABLE

PHASE: (3 BITS)

<u>BIT CODE</u>	<u>PHASE</u>
000	(NOT USED)
001	GROUND CHECKOUT
010	START PREPARATION
011	START
100	MAINSTAGE
101	SHUTDOWN
110	POST SHUTDOWN
111	(SPARE)

13M15000F

TABLE VIII (Continued)
ENGINE STATUS WORD

SELF TEST STATUS: (LAST 2 BITS)

BIT CODE	ENGINE STATUS
00	(NOT USED)
01	ENGINE OK
10	COMPONENT FAILED
11	ENGINE LIMIT EXCEEDED

MODE BY PHASE (3 BITS)

PHASE	GROUND	START				POST SHUT-DOWN
BIT CD.	CHECKOUT	PREPARATION	START	MAINSTAGE	SHUTDOWN	
000	← NOT USED →					
001	STANDBY	PURGE SEQ. NO. 1	START INITIA-TION	NORMAL CONTROL	THROTTL-ING TOMPL	STANDBY
010	SPARE	PURGE SEQ. NO. 2	THRUST BUILD-UP	SPARE	MPL TO ZERO THRUST	OXIDIZER DUMP
011	CHECKOUT COMPLETE	PURGE SEQ. NO. 3	THRUST LIMITING	THRUST LIMITING	PROP. VALVES CLOSED	FUEL DUMP
100	COMPON-ENT CHECKOUT	PURGE SEQ. NO. 4	SPARE	(SPARE)	FAIL SAFE PNEUMAT-IC	ABORT TURN-AROUND SEQ. NO. 1
101	SPARE	ENGINE READY	(SPARE)	(SPARE)	(SPARE)	ABORT TURN-AROUND SEQ. NO. 2
110	(SPARE)	(SPARE)	(SPARE)	(SPARE)	(SPARE)	ENGINE READY
111	(SPARE)	(SPARE)	(SPARE)	(SPARE)	(SPARE)	(SPARE)

EXAMPLE OF WORD CODE AND INTERPRETATION

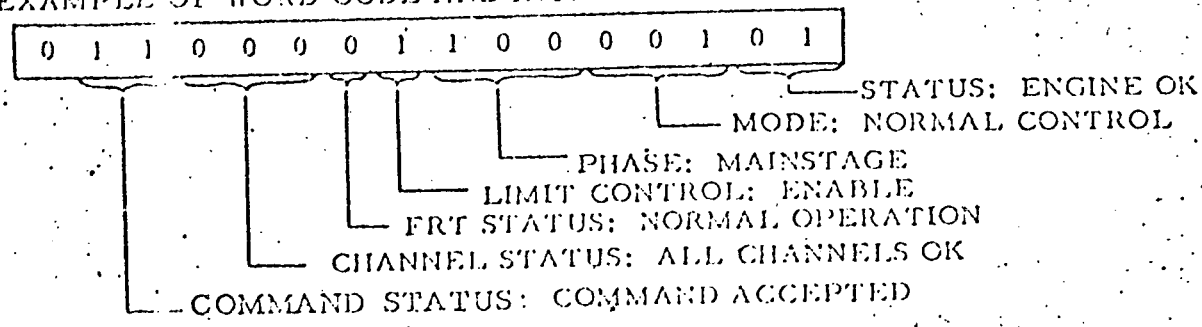


TABLE IX
SENSOR RANGES AND REDUNDANCY LEVELS

PARAMETER	REDUNDANCY	SENSOR RANGE
LOW PRESSURE FUEL TURBOPUMP		
DISCHARGE PRESSURE	3	0 to 400 PSIA
DISCHARGE TEMPERATURE	3	-423 to +700F (R = 5000 OHMS)
SHAFT SPEED	2*	0 to 20,000 RPM
FUEL FLOWRATE	4	0 to 18,000 GPM
RADIAL VIBRATION	1	0 to 300 g RMS
HIGH PRESSURE FUEL TURBOPUMP		
DISCHARGE PRESSURE	1	0 to 8000 PSIA
SHAFT SPEED	2	0 to 45,000 RPM
RADIAL VIBRATION	1	0 to 300 g RMS
TURBINE DISCHARGE TEMPERATURE	2	0 to 2300F (R = 50 OHMS)
FUEL PREBURNER		
CHAMBER PRESSURE	1	0 to 7000 PSIA
LONGITUDINAL VIBRATION	1	0 to 1000 g RMS
LOW PRESSURE OXIDIZER TURBOPUMP		
DISCHARGE PRESSURE	2	0 to 600 PSIA
SHAFT SPEED	2*	0 to 5500 RPM
RADIAL VIBRATION	1	0 to 300 g RMS

*One level of redundancy is used for checkout only.

TABLE IX
SENSOR RANGES AND REDUNDANCY LEVELS

PARAMETER	REDUNDANCY	SENSOR RANGE
HIGH PRESSURE OXIDIZER TURBOPUMP		
DISCHARGE TEMPERATURE	3	-423 to +700F (R = 5000 ohms)
DISCHARGE PRESSURE	3	0 to 7000 PSIA
BOOST STAGE DISCHARGE PRESSURE	1	0 to 9500 PSIA
OXIDIZER TANK PRESSURANT PRESSURE	2	0 to 6500 PSIA
SHAFT SPEED	2	0 to 35,000 RPM
OXIDIZER FLOWRATE	4	0 to 7000 GPM
RADIAL VIBRATION	1	0 to 300 g RMS
TURBINE DISCHARGE TEMPERATURE	2	0 to 2300F (R = 50 ohms)
OXIDIZER PREBURNER		
CHAMBER PRESSURE	1	0 to 7000 PSIA
LONGITUDINAL VIBRATION	1	0 to 1000 g RMS
MAIN COMBUSTION CHAMBER		
PRESSURE	3	0 to 3500 PSIA
FUEL INJECTION PRESSURE	1	0 to 4500 PSIA
COOLANT TEMPERATURE	1	-423 to +700F (R = 1330 ohms)
COOLANT PRESSURE	1	0 to 6500 PSIA
LONGITUDINAL VIBRATION	1	0 to 1000 g RMS
HYDRAULIC SYSTEM PRESSURE		
	2	0 to 4000 PSIA
PNEUMATIC CONTROL SYSTEM		
OXIDIZER SYSTEM PURGE PRESSURE	1	0 to 1000 PSIA
FUEL SYSTEM PURGE PRESSURE	1	0 to 1000 PSIA
HIGH PRESSURE OXIDIZER TURBOPUMP INTERMEDIATE SEAL PURGE	2	0 to 100 PSIA
OXIDIZER BLEED VALVE CONTROL PRESSURE	1	0 to 1000 PSIA
FUEL LIFT-OFF SEAL AND BLEED VALVE CONTROL PRESSURE	1	0 to 1000 PSIA

TABLE IX
SENSOR RANGES AND REDUNDANCY LEVELS

PARAMETER	REDUNDANCY	SENSOR RANGE
HIGH PRESSURE OXIDIZER TURBOPUMP	1	0 to 1000 PSIA
TURBINE SEAL PURGE PRESSURE		
CONTROLLER		
PRESSURE	2	0 to 50 PSIA
TEMPERATURE - OPERATING	2	-320 to +300 F (R =200 ohms)
TEMPERATURE - NON-OPERATING	1	-320 to +300 F (R =200 ohms)
FLOW CONTROL VALVES		
MAIN FUEL VALVE		
ACTUATOR ROTATIONAL TRAVEL	2	85 DEGREES NOMINAL
ACTUATOR RVDT SENSITIVITY	2	0.0529 VOLTS p-p/deg NOMINAL
SERVOVALVE SPOOL LVDT SENSITIVITY	2	31.25 VOLTS p-p/in NOMINAL
MAIN OXIDIZER VALVE		
ACTUATOR ROTATIONAL TRAVEL	2	85 DEGREES NOMINAL
ACTUATOR RVDT SENSITIVITY	2	0.0529 VOLTS p-p/deg NOMINAL
SERVOVALVE SPOOL LVDT SENSITIVITY	2	31.25 VOLTS p-p/in NOMINAL
OXIDIZER PREBURNER OXIDIZER VALVE		
ACTUATOR ROTATIONAL TRAVEL	2	80 DEGREES NOMINAL
ACTUATOR RVDT SENSITIVITY	2	0.0563 VOLTS p-p/deg NOMINAL
SERVOVALVE SPOOL LVDT SENSITIVITY	2	31.25 VOLTS p-p/in NOMINAL
FUEL PREBURNER OXIDIZER VALVE		
ACTUATOR ROTATIONAL TRAVEL	2	80 DEGREES NOMINAL
ACTUATOR RVDT SENSITIVITY	2	0.0563 VOLTS p-p/deg NOMINAL
SERVOVALVE SPOOL LVDT SENSITIVITY	2	31.25 VOLTS p-p/in NOMINAL

TABLE IX
SENSOR RANGES AND REDUNDANCY LEVELS

PARAMETER	REDUNDANCY	SENSOR RANGE
MAIN COMBUSTION CHAMBER COOLANT VALVE		
ACTUATOR ROTATIONAL TRAVEL	-	80 DEGREES NOMINAL
ACTUATOR RVDT SENSITIVITY	2	0.0563 VOLTS P-P/199 NOMINAL
SEARVALVE SPOOL LVDT SENSITIVITY	2	31.25 VOLTS P-P/in NOMINAL
FUEL BLEED VALVE		
STROKE	-	0 to 0.235±.002 in
LVDT SENSITIVITY	1	PROPORTIONAL TO SQUARE ROOT OF DISTANCE FROM SENSITIVE FACE
OXIDIZER BLEED VALVE		
STROKE	-	0 to 0.235±.002 in
LVDT SENSITIVITY	1	PROPORTIONAL TO SQUARE ROOT OF DISTANCE FROM SENSITIVE FACE

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TABLE XI

SENSOR DATA REASONABLENESS AND COMPARISON TEST REQUIREMENTS

PARAMETER	REASONABLENESS LIMITS (NOTE 1)		COMPARISON FAILURE LIMITS (NOTE 2)	NOTES
	MINIMUM	MAXIMUM		
Low Pressure Fuel Turbopump				
Discharge Pressure	30	375 psia	4% FS	
Discharge Temperature	36	50 R	0.5 R	5
Flowrate (Volumetric)	4000	18000 gpm	10%, 1.5% FS	3
High Pressure Fuel Turbopump				
Turbine Discharge Temperature	800	2600 R	100 R	
Shaft Speed	10000	43000 RPM	10%, 1.5% FS	3
Low Pressure Oxidizer Turbopump				
Discharge Pressure	150	550 psia	4% FS	
High Pressure Oxidizer Turbopump				
Discharge Pressure	1750	6500 psia	4% FS	
Discharge Temperature	170	200 R	1.5 R	5
Turbine Discharge Temperature	800	2600 R	100 R	
Shaft Speed	8000	35000 RPM	10%, 1.5% FS	3
Oxidizer Tank Pressurant Pressure	1000	6000 psia	4% FS	
Flowrate (Volumetric)	3200	6800 gpm	10%, 1.5% FS	3
Main Combustion Chamber Pressure	1100	3500 psia	4% FS	
Hydraulic System Pressure	No Minimum	4000 psia	4% FS	
Actuator Position All Sensors	-2	102%	See Note	4

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SENSOR DATA REASONABLENESS AND COMPARISON TEST REQUIREMENTS

PARAMETER	REASONABLENESS LIMITS (NOTE 1)		COMPARISON FAILURE LIMITS (NOTE 2)	NOTES
	MINIMUM	MAXIMUM		
φ Pneumatic Control System HPOT Intermediate Seal Purge Pressure	No Minimum	95 psia	4% FS	

NOTES:

1. Unless noted otherwise, these requirements apply only in the 40 to 112 percent normal thrust range.
2. Comparison Test is defined as follows:

For three active redundant measurements, the value of the measurement being tested is compared with each of the other two measurements. The Sensor fails the test if it differs from both of the other measurements by more than the limit. For two active redundant measurements, the value of one measurement is compared with the other measurement. A failure is assumed if the comparison limit is exceeded.

3. This is a comparison between digitized pulse rate signals. Percent is percent of full scale. First number is for operation below 40% NPL. Second number is for operation at 40% NPL and higher.
4. Each Sensor output is compared with the Controller position reference for the actuator channel associated with that Sensor. The Actuator position Comparison Test is applicable at all thrust levels.
5. These cryogenic temperature sensor requirements shall apply starting 10 minutes after initiation of propellant recirculation (Purge Sequence No. 3) during the Start Preparation phase. They shall apply starting 5 minutes after initiation of propellant recirculation (Abort Turnaround Sequence No. 2) during Abort Turnaround.

ABBREVIATIONS:

FS = Full Scale

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TABLE XI
FLIGHT SENSOR DATA PROCESSING FUNCTIONS

Subsystem and Parameter	Number of Sensor Outputs Processed	Preflight Automatic Calibration	Reasonableness Test	Comparison Test	Measurement Use	Type of Averaging (Note 1)
<u>Low Pressure Fuel Turbopump</u>						
Discharge Pressure	3	X	X	X	PC, SV, MR	(A1 + B1 + A2)/3
Discharge Temperature	3		X	X	PC, SV, MR	(A1 + B1 + A2)/3
Shaft Speed	1				MR	A
Radial Vibration	1				MR	A
<u>Fuel Flowmeter</u>						
Volumetric Flowrate	3		X	X	PC, MR	(A1 + B1 + A2)/3
<u>High-Pressure Fuel Turbopump</u>						
Discharge Pressure	1				MR	A
Shaft Speed	2		X	X	LC, MR	A or B
Radial Vibration	1				MR	A
φ Turbine Discharge Temperature	2		X	X	LC, MR	(A1 + A2)/2
<u>Fuel Preburner</u>						
Chamber Pressure	1				MR	A
Longitudinal Vibration	1				MR	A1

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TABLE XI (Continued)

FLIGHT SENSOR DATA PROCESSING FUNCTIONS

Subsystem and Parameter	Number of Sensor Outputs Processed	Preflight Automatic Calibration	Reasonableness Test	Comparison Test	Measurement Use	Type of Averaging (Note 1)
<u>Low Pressure Oxidizer Turbopump</u>						
Discharge Pressure	2	X	X	X	SV, MR	(A1 + A2)/2
Shaft Speed	1				MR	A
Radial Vibration	1				MR	A
<u>High Pressure Oxidizer Turbopump</u>						
Discharge Pressure	3	X	X	X	PC, MR	(A1 + B1 + A2)/3
Discharge Temperature	3		X	X	PC, SV, MR	(A1 + B1 + A2)/3
Boost Stage Discharge Pressure	1				MR	A
Shaft Speed	2		X	X	LC, MR	A or B
Radial Vibration	1				MR	A
<u>Turbine Discharge Temperature</u>						
	2		X	X	LC, MR	(A1 + A2)/2
<u>Oxidizer Tank Pressurant Pressure</u>						
	2		X	X	LC, MR	(A + B)/2
<u>Oxidizer Flowmeter</u>						
Volumetric Flowrate	3		X	X	PC, MR	(A1 + B1 + A2)/3

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TABLE XI (Continued)
FLIGHT SENSOR DATA PROCESSING FUNCTIONS

Subsystem and Parameter	Number of Sensor Outputs Processed	Preflight Automatic Calibration	Reasonableness Test	Comparison Test	Measurement Use	Types of Averaging (Note 1)
<u>Oxidizer Preburner</u>						
Chamber Pressure	1				MR	A
Longitudinal Vibration	1				MR	A1
<u>Main Combustion Chamber</u>						
Pressure	3	X	X	X	PC, MR	(A1 + B1 + A2)/3
Fuel Injector Pressure	1				MR	A
Coolant Pressure	1				MR	A
Coolant Temperature	1				MR	A
Longitudinal Vibration	1				MR	A1
<u>Hydraulic System</u>						
Pressure	2		X	X	SV, EC, MR	(A + B)/2
<u>Flow Control Valve Positions</u>						
φ Main Fuel Valve						
Servo valve	2				(Note 2)	
Actuator	2		X	X	SV, MR, EC	A1 or A2

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Table XI (Continued)

FLIGHT SENSOR DATA PROCESSING FUNCTIONS

Subsystem and Parameters	Number of Sensor Outputs Processed	Preflight Automatic Calibration	Reasonableness Test	Comparison Test	Measurement Use	Type of Averaging (Note 1)
<u>Main Oxidizer Valve</u>						
Servovalve	2				(Note 2)	
Actuator	2	X	X	X	SV, MR, EC	A1 or A2
<u>Chamber Coolant Valve</u>						
Servovalve	2				(Note 2)	
Actuator	2	X	X	X	SV, MR, EC	A1 or A2
<u>Fuel Preburner Oxidizer Valve</u>						
Servovalve	2				(Note 2)	
Actuator	2	X	X	X	SV, MR, EC	A1 or A2
<u>Oxidizer Preburner Oxidizer Valve</u>						
Servovalve	2				(Note 2)	
Actuator	2	X	X	X	SV, MR, EC	A1 or A2
<u>Fuel Bleed Valve</u>	1				MR, EC	A
<u>Oxidizer Bleed Valve</u>	1				MR, EC	A

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FLIGHT SENSOR DATA PROCESSING FUNCTIONS

Subsystem and Parameters	Number of Sensor Outputs Processed	Preflight Automatic Calibration	Reasonableness Test	Comparison Test	Measurement Use	Type of Averaging (Note 1)
<u>Controller</u>						
Internal Pressure	2				MR, EC	A or B
Internal Temperature	2				MR, EC	(A1 + A2)/2
<u>Pneumatic Control System</u>						
Oxidizer System Purge Pressure	1				SV, MR, EC	A
Fuel System Purge Pressure	1				SV, MR, EC	A
Oxidizer Bleed Valve Control Pressure	1				SV, MR, EC	A
Fuel Liftoff Seal and Bleed Valve Control Pressure	1				SV, MR, EC	A
HPOT Intermediate Seal Purge Pressure	2	X		X	LC, SV, MR, EC	A or B
HPOT Turbine Seal Purge Pressure	1				SV, MR, EC	A

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TABLE XI (Concluded)
FLIGHT SENSOR DATA PROCESSING FUNCTIONSABBREVIATIONS:

Sensor Output

A1 = Sensor No. 1 output A
B1 = Sensor No. 1 output B
A2 = Sensor No. 2 output A
B2 = Sensor No. 2 output B

Functional Use

PC = Performance Control
LC = Temperature Limit Control or Limit Shutdown
SV = Status Verification and Engine Ready
MR = Maintenance Recording
EC = Engine Checkout

GENERAL NOTES:

1. Averaging with failed sensors out is not shown. See 3.2.1.1.8.5 for averaging with failed sensor condition.
2. Servovalve position is not used in software program.

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φ TABLE XI

SENSOR CALIBRATION CURVE FIT EQUATIONS

TYPE OF SENSOR	TYPE OF SENSOR CURVE FIT EQUATION
Pressure	$P = B_1 V + B_0$
Performance and Limit Control Temperature Sensors (Note 1)	$T = B_4 V^4 + B_3 V^3 + B_2 V^2 + B_1 V + B_0$
Position	$X = B_1 V + B_0$
Volumetric Flow Meter	$Q = B_1 S + B_0$
Turbine Speed	$N = B_1 S$

PARAMETER DEFINITIONS

B = Equation Coefficient (Data Constant in Computer Program)

V = Measured Sensor Circuit Output Voltage

S = Measured Sensor Pulse Rate Output

T = Temperature

X = Position

Q = Volumetric Flow Rate

N = Rotational Speed

NOTES

- φ1. Performance and Limit Control Temperature Sensors are at the following locations:
- HPOT Turbine Discharge
 - HPFT Turbine Discharge
 - LPFT Discharge
 - HPOT Discharge

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TABLE XII

NOTES:

1. Response to failures shall be accomplished as defined by the symbols below. "Identify failure" shall mean: the failure identification number, the associated test number (if applicable) and the failed parameter value shall be entered into the table of data transmitted to the recorder (see RC1007) in the vehicle, and Component Failed shall be indicated by the Engine Status Word unless a Limit Shutdown condition exists (3.2.1.1.7.2) in which case Engine Limit Exceeded shall be indicated.

ϕI = Identify failure and inhibit initiation of the commanded operating mode normally next in sequence. Purge sequences or other operating procedures shall be continued uninterrupted (by the failure indication) to their normal completion at the end of the operating mode. The inhibit can be overridden only by a repeat of the command in effect at the time of the failure. Up to five current failures with I responses may be overridden by a repeat of the command in effect, for each failure. The overrides shall remain in effect until a Controller Reset command is issued. Other valid commands may be accepted, but acceptance of those commands will not override a failure with an I response.

ϕS = When failure has been verified three times in succession, identify failure and initiate Limit Shutdown as defined by and if permitted by conditions imposed in 3.2.1.1.5.2.2.

ϕH = Identify failure and halt checkout test procedure temporarily until the controller has responded to a Status Request command at which time the procedure shall resume and continue to its normal completion at the end of the operating mode. Entry into the Checkout Complete Mode shall be inhibited until all indicated failures have been corrected.

ϕR = For non-redundant channels, identify failure and continue operation. For redundant channels, identify failure and switch to continued operation on a redundant channel, if the failed channel is active and the failure has been verified three times in succession.

ϕPS = When the failure has been verified three times in succession identify failure and initiate Pneumatic Shutdown as defined in 3.2.1.1.5.2.3.

NA = No Action. Function is not applicable or no tests are made during indicated phase and parameter is for maintenance recording only.

2. The failure mode test shall be made as indicated by the symbols below. The tables specifying the Operational Function Requirements for each engine phase, other than Checkout, shall be used to define the normal operating position of a valve or the energized state of a solenoid coil.

ϕAC = Perform checkout tests as described in Table II.

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- BITE = Failure indicated when built-in test equipment signal of component operational status is not correct for the engine status at the time of the test.
- CC = Failure indicated when the solenoid coil current of the valve is not correct for the energized state of the coil as determined by the engine status at the time of the test.
- CH = Failure indicated when an actuator channel is determined to be inoperative due to a servovalve channel failure or an actuator position error as defined in 3.2.1.1.7.1.
- CO = Perform comparison tests for redundant sensors as described by 3.2.1.1.8.4.
- EL = Failure indicated when sensed parameter is out of limits defined for that parameter in RC1007 table titled "Engine Limit Control Shutdown Parameters."
- ER = Failure indicated when sensed Engine Ready parameter is out of limits specified in Table V.
- MJ = Failure indicated by Message Reject code as defined in 3.2.1.1.1.2.
- NFD = Failure indicated when sensed propellant temperature is less than level indicated in 3.2.1.1.3.1.1.
- PL = Failure indicated when the sensed purge pressure is at a level which is not correct for the energized state of the purge valve solenoid coils as determined by the engine status at the time of the test.
- POS = Failure indicated when the valve actuator position is not correct for the normal operating position of the valve as determined by the engine status at the time of the test.
- RE = Perform reasonableness tests for redundant sensors as described in 3.2.1.1.8.3. See Table XII for reasonableness limits.
- ST = Controller Self Test is defined in 3.1.1.1.2.
- VEC = Failure of a Vehicle/Engine Command Channel indicated by comparison tests as specified by 3.2.1.1.1.2.1.1 or by transmission failures as indicated by built-in test equipment.
- VL = Failure indicated when the power bus monitor voltage output is less than (TBD) volts DC or greater than (TBD) volts DC.

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3. First letter indicates failure condition response if failure occurs before ignition confirmed. Second letter indicates failure condition response after ignition has been confirmed (See Table VI).
4. Report failure status during Abort Turnaround only, otherwise no action is taken.
5. Inhibit action on sequence applicable during Abort Turnaround only. When in other mode than Abort Turnaround, report failure status and continue operation.
6. Channel includes sensor, harness, connectors, and controller input or output electronics.
7. Comparison tests shall be performed when reasonableness tests are not applicable.
8. The failure response indicated by the first letter is applicable when the failure is the first in redundant components. The failure response indicated by the second letter is applicable when a subsequent failure has been verified.
9. Controller channel includes a computer channel, power supply and input/output electronics.

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TABLE XIII
OPERATIONAL FUNCTION REQUIREMENTS FOR
START PREPARATION

Step	Operation	Time from Start of Sequence (seconds)	Remarks
PART A - PURGE SEQUENCE NO. 1 (Oxidizer System and Intermediate Seal Purges)			
φ1	Update Engine Status Word to Purge Sequence No. 1 mode of Start Preparation phase and to indicate Engine OK	0	Begin Start Preparation Phase
φ2	Energize Emergency Shutdown Control Valve	--	
φ3	Energize all actuator fail safe valves	--	
φ4	Energize HPOT Intermediate Seal Purge Control Valve	--	Start HPOT Intermediate Seal Purge
5	Energize GN2 System Purge Control Valve	--	Start Oxidizer System Purge
φ6	Verify HPOT Intermediate Seal Purge Pressure is greater than 40 psia	0.20	
φ7	Verify Oxidizer System Purge Pressure is greater than 200 psia	--	Note 4
φ8	Verify HPOT Turbine Seal Purge Pressure is greater than 200 psia	--	Note 4
PART B - PURGE SEQUENCE NO. 2 (Fuel System Purge)			
φ9	Change Engine Status Word to indicate Purge Sequence No. 2 mode	0	
10	Energize Fuel System Purge Control Valve	--	Start Fuel System Purge
φ11	Verify Fuel System Purge Pressure is greater than 300 psia	0.20	Note 4
PART C - PURGE SEQUENCE NO. 3 (Propellant Recirculation)			
φ12	Change Engine Status Word to indicate Purge Sequence No. 3 mode	0	
13	De-energize Fuel System Purge Control Valve	--	Stop Fuel System Purge
φ14	De-energize HPOT Intermediate Seal Purge Control Valve	--	Cut off HPOT Intermediate Seal Purge

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TABLE XIII (Continued)

Step	Operation	Time from Start of Sequence (seconds)	Remarks
15	Energize Lift-off Seal and Bleed Valve Control Valve	--	Open bleed valves
φ 16	Verify Oxidizer Bleed Valve Control Pressure is greater than 650 psia	0.20	Note 4
φ 17	Verify Fuel Lift-off Seal and Bleed Valve Control Pressure is greater than 650 psia	--	Note 4
φ 18	Verify Fuel System Purge Pressure is less than 50 psia	--	Note 4
φ 19	Verify HPOT Intermediate Seal Purge Pressure is less than 30 psia	--	

PART D - PURGE SEQUENCE NO. 4 (Fuel System Purge after Propellant Drop)

φ 20	Change Engine Status Word to indicate Purge Sequence No. 4 mode	0	
21	Energize Fuel System Purge Control Valve	--	Start Fuel System Purge
φ 22	Verify Fuel System Purge Pressure greater than 300 psia	0.20	Note 4
23	Verify system conditions and change Engine Status Word to indicate Engine Ready when system conditions satisfy requirements of 3.2.1.1.4.5	180	

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GENERAL NOTES:

- φ1. The controller response for a failure to satisfy verification test specified for this sequence shall be as defined in Table III.
2. Unless otherwise noted, functional operations once initiated, shall continue until changed by a subsequent operation, and tests made to verify a functional operation shall be terminated when the functional operation is negated.
3. Operations listed in this table shall be performed in the listed sequence and with the indicated timing. Where time for an operation is not stated the operation shall be performed in the least time practical after the previous operation.
- φ4. Verification of pressure level with a non-redundant sensor shall be performed by comparing the sensor output to a fixed voltage equivalent to the pressure level specified.

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TABLE XIV

PROPELLANT CONDITIONS REQUIRED FOR ENGINE
READY STATUS SIGNAL

Fuel Temperature at Low Pressure Fuel Turbopump
discharge - R

Less than	42
Greater than	37

Fuel Pressure at Low Pressure Fuel Turbopump
discharge - psia

Less than	50
Greater than	30

Oxidizer Temperature at High Pressure Oxidizer
Turbopump discharge - R

Less than	170.5
Greater than	163

Oxidizer Pressure at Low Pressure Oxidizer Turbo-
pump discharge - psia

Less than	120
Greater than	85

Fuel Condition based on LPFT discharge conditions shall satisfy the following requirements:

Fuel temperature (TH) shall have remained within a 0.6 R band (peak-to-peak excursion) for at least the previous 3 minutes.

Fuel subcooling (TSH) shall be equal to or greater than 0.6 R. Fuel subcooling is defined as:

$$TSH = A*PH^{**2}+B*PH+C-TH$$

- * Asterisk represents multiplication when used in an equation.
- ** Double asterisk represents exponentiation when used in an equation.

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TABLE XIV (Concluded)

Oxidizer condition based on LPOT discharge pressure and HPOT discharge temperature shall satisfy the following requirements:

Oxidizer temperature (TO) shall have remained within a 1.5 R band (peak-to-peak excursion) for at least the previous 3 minutes.

Oxidizer subcooling (TSO) shall be equal to or greater than 1.5 R.
Oxidizer subcooling is defined as:

$$TSO = D \cdot PO^{**2} + E \cdot PO + F - TO$$

Parameter Definitions:

TH = R - measured hydrogen temperature at LPFT discharge

TO = R - measured oxygen temperature at HPOT discharge

TSH = R - computed hydrogen subcooling

TSO = R - computed oxygen subcooling

PH = psia - measured hydrogen pressure at LPFT discharge

PO = psia - measured oxygen pressure at LPOT discharge

A, B, C, D, E, F = equation constants

* Asterisk represents multiplication when used in an equation.
** Double asterisk represents exponentiation when used in an equation.

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TABLE XV

OPERATIONAL FUNCTION REQUIREMENTS FOR
ENGINE START SEQUENCE

Step	Operation	Time from Start of Sequence (seconds)	Remarks
φ1	Update Engine Status Word to Start Initiation mode of Start phase and to indicate Engine OK	0	Begin Start phase
2	De-energize GN2 System Purge Control Valve	--	
3	De-energize Fuel System Purge Control Valve	--	
4	De-energize Lift-off Seal and Bleed Valve Control Valve	--	
φ5	Energize HPOT Intermediate Seal Purge Control Valve	--	
6	Energize all igniters	---	
7	Verify spark rate and voltage of all igniters	--	
φ8	Ramp Main Fuel Valve full open at 200 percent per second actuator rate	--	Establish fuel flow
φ9	Ramp Chamber Coolant Valve to 30 percent actuator position at TBD percent per second actuator rate	--	
φ10	Ramp Fuel and Oxidizer Preburner Oxidizer Valves to 22 percent actuator position at TBD percent per second actuator rate	0.10	Starts ignition flow
φ11	Ramp Main Oxidizer Valve to 35 percent actuator position at TBD percent per second actuator rate	--	Establish main chamber oxidizer flow
φ12	Verify Fuel System Purge Pressure less than 50 psia	0.20	Note 5

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TABLE XV (Continued)

Step	Operation	Time from Start of Sequence (seconds)	Remarks
φ13	Verify Lift-off Seal and Bleed Valve Control Pressure is less than 50 psia	--	Note 5
φ14	Verify HPOT Intermediate Seal Purge Pressure is greater than 40 psia	--	
φ15	Ramp Fuel Preburner Oxidizer Valve to 28 percent actuator position at TBD percent per second actuator rate	0.50	Build up fuel turbo-pump power
φ16	Initiate closed-loop thrust control (proportional error control only)	0.60	
φ17	Ramp Oxidizer Preburner Oxidizer Valve to 38 percent actuator position at TBD percent per second actuator rate	--	Build up oxidizer turbopump power
φ18	Verify Oxidizer System Purge Pressure less than 50 psia	1.00	Note 5
φ 19	Verify HPOT Turbine Seal Purge Pressure is less than 50 psia	--	Note 5
φ 20	Verify Main Combustion Chamber Pressure greater than chamber pressure at 5 percent NPL and less than chamber pressure at 20 percent NPL	1.90	Verify ignition and adequate start thrust. See Figure 6.
φ 21	Change Engine Status Word to indicate Thrust Buildup mode	--	Start thrust buildup
φ 22	Activate integral thrust error control	2.00	
φ 23	Start increasing thrust reference ramp to command level at 3200 lb/10 ms rate (See Note 4)	--	
φ 24	Ramp Main Oxidizer Valve full open at 35 percent per second actuator rate	--	
25	Initiate scheduled operation of CCV as a function of thrust reference when the Thrust Reference reaches MPL	2.40 (Typical)	
φ 26	Initiate scheduled operation of the MOV and MFV as a function of computed thrust when the computed thrust reaches NPL	3.25 (Typical)	
27	Initiate closed-loop mixture ratio control	3.25	

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TABLE XV (Concluded)

Step	Operation	Time from Start of Sequence (seconds)	Remarks
28	Change Engine Status Word to indicate Normal Control mode of Mainstage	--	Begin Mainstage phase
29	De-energize all igniters	--	

GENERAL NOTES:

1. The controller response for a failure to satisfy verification tests specified for this sequence shall be as defined in Table III.
2. Unless otherwise noted, functional operations once initiated, shall continue until changed by a subsequent operation, and tests made to verify a functional operation shall be terminated when the functional operation is negated.
3. Operations listed in this table shall be performed in the listed sequence and with the indicated timing. Where time for the operation is not stated the operation shall be performed in the least time practical after the previous operation.
4. Switch to operation with vehicle thrust command reference after ramp reaches command reference value.
5. Verification of pressure level with a non-redundant sensor shall be performed by comparing the sensor output to a fixed voltage equivalent to the pressure level specified.

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TABLE XVI

OPERATIONAL FUNCTION REQUIREMENTS FOR ENGINE
SHUTDOWN SEQUENCE FROM MAINSTAGE

Step	Operation	Time from Start of Sequence (seconds)	Remarks
PART A - SEQUENCE TO MPL THRUST REFERENCE LEVEL			
φ1	Update Engine Status Word to "Throttling to MPL" mode of Shutdown phase	0	Shutdown normally begins here
2	Start decreasing thrust reference at 4800 lb/10 ms	--	
3	Start Part B of Sequence when thrust reference reaches MPL	Not Applicable	
PART B - SEQUENCE FROM MPL REFERENCE LEVEL			
φ4	Change Engine Status Word to indicate MPL to Zero Thrust mode	0	
φ5	Ramp Main Oxidizer Valve closed at 90 percent per second actuator rate	--	
φ6	Ramp Oxidizer Preburner Oxidizer Valve closed at 150 percent per second actuator rate	0.1	
7	Ramp Fuel Preburner Oxidizer Valve closed at 150 percent per second actuator rate	--	
φ8	Ramp Main Fuel Valve closed at 200 percent per second actuator rate	0.60	
φ9	Ramp Coolant Control Valve closed at 50 percent per second actuator rate	--	
PART C - SEQUENCE AFTER PROPELLANT VALVES ARE CLOSED			
10	Verify MFV, MOV, OPOV, FPOV and CCV closed	1.15	
φ11	Change Engine Status Word to indicate Propellant Valves Closed mode	--	
φ12	De-energize HPOT intermediate Seal Purge Control Valve	2.05	Cutoff intermediate seal purge

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TABLE XVI (Concluded)

Step	Operation	Time from start of Sequence (seconds)	Remarks
φ13	Verify all purge and lift-off seal pressures less than 50 psia (Note 4) except for HPOT Intermediate Seal Purge Pressure which shall be less than 30 psia	2.25	
14	De-energize all fail-safe valves	--	
φ15	De-energize Emergency Shutdown Control Valve	--	
16	Put system in standby condition and change Engine Status Word to Post Shutdown Standby mode	--	Transition to Post Shutdown

GENERAL NOTES:

- φ1 The controller response for a failure to satisfy verification tests specified for this sequence shall be as defined in Table III.
2. Unless otherwise noted, functional operations once initiated, shall continue until changed by a subsequent operation, and tests made to verify a functional operation shall be terminated when the functional operation is negated.
3. Operations listed in this table shall be performed in the listed sequence and with the indicated timing. Where time for the operation is not stated the operation shall be performed in the least time practical after the previous operation.
- φ4. Verification of pressure level with a non-redundant sensor shall be performed by comparing the sensor output to a fixed voltage equivalent to the pressure level specified.

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TABLE XVII

OPERATIONAL FUNCTION REQUIREMENTS FOR
PROPELLANT DUMP

Step	Operation	Time from Start of Sequence (Seconds)	Remarks
PART A - SEQUENCE TO INITIATE OXIDIZER DUMP (Oxidizer Dump command received)			
φ1	Change Engine Status Word to indicate Oxidizer Dump mode	0	
2	Verify averaged Hydraulic System Pressure is 3000 plus 560, minus 360 psia	--	
φ3	Verify all propellant valves closed	--	
4	Energize Main Oxidizer Valve Fail-safe Valve	--	
5	Ramp Main Oxidizer Valve full open at TBD percent per second actuator rate	--	Starts oxidizer pump
PART B - SEQUENCE TO INITIATE FUEL DUMP (Fuel Dump command received)			
φ6	Change Engine Status Word to indicate Fuel Dump mode	0	
φ7	Ramp Main Oxidizer Valve full closed at TBD percent per second actuator rate	--	Stop oxidizer dump
φ8	Verify MOV Closed	--	
9	De-energize MOV Fail-safe Valve	0.7	
10	Energize Fuel System Purge Control Valve	--	Start Fuel System purge
φ11	Verify Fuel System Purge Pressure greater than 300 psia	0.9	Note 4
12	De-energize Fuel System Purge Control Valve	10.9	Shut-off Fuel System Purge
φ13	Verify Fuel System Purge Pressure less than 50 psia	11.1	Note 4
14	Energize MFV Fail-safe valve	--	

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TABLE XVII (Concluded)

Step	Operation	Time from Start of sequence (Seconds)	Remarks
φ15	Ramp Main Fuel Valve full open at TBD percent per second actuator rate	--	Start fuel dump
16	Verify MFV open	11.5	
φPART C - SEQUENCE TO TERMINATE PROPELLANT DUMP (Terminate Propellant Dump command received)			
φ17	Ramp propellant valve full closed at TBD percent per second actuator rate	0	Stop propellant dump
φ18	Verify all propellant valves closed	0.4	
19	De-energize actuator fail-safe valves	--	
20	Return system to Post Shutdown Standby mode status	--	

GENERAL NOTES:

- φ1. The controller response for a failure to satisfy verification tests specified for this sequence shall be as defined in Table III.
2. Unless otherwise noted, functional operations once initiated, shall continue until changed by a subsequent operation, and tests made to verify a functional operation shall be terminated when the functional operation is negated.
- φ3. Operations listed within each part of this table shall be performed in the listed sequence within each and with the indicated timing. Where time for the operation is not stated the operation shall be performed in the least time practical after the previous operation.
- φ4. Verification of pressure level with a non-redundant sensor shall be performed by comparing the sensor output to a fixed voltage equivalent to the pressure level specified.

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TABLE XVIII

OPERATIONAL FUNCTION REQUIREMENTS FOR
ABORT TURNAROUND

<u>Step</u>	<u>Operation</u>	<u>Time from Start of Sequence (Seconds)</u>	<u>Remarks</u>
PART A - ABORT TURNAROUND SEQUENCE NO. 1			
φ1	Change Engine Status Word to indicate Abort Turnaround Sequence No. 1 mode	0	
φ2	Energize Emergency Shutdown Control Valve	--	
φ3	Energize all actuator fail safe Valves	--	
φ4	Energize HPOT Intermediate Seal Purge Control Valve	--	Start purges
5	Energize GN2 System Purge Control Valve	--	
6	Energize Fuel System Purge Control Valve	--	
φ7	Verify HPOT Intermediate Seal Purge Pressure is greater than 40 psia	0.20	
φ8	Verify Oxidizer System purge pressure is greater than 200 psia	--	Note 4
φ9	Verify HPOT Turbine Seal Purge Pressure is greater than 200 psia	--	Note 4
φ10	Verify Fuel System Purge Pressure is greater than 300 psia	--	Note 4
PART B - ABORT TURNAROUND SEQUENCE NO. 2			
φ11	Change Engine Status Word to indicate Abort Turnaround Sequence No. 2 mode	0	
φ12	Energize Lift-off Seal and Bleed Valve Control Valve	--	Start propellant recirculation
φ13	Verify Oxidizer Bleed Valve Control Pressure is greater than 650 psia	0.20	Note 4
φ14	Verify Fuel Lift-off Seal and Bleed Valve Pressure is greater than 650 psia	--	Note 4
φ15	Verify system conditions and change Engine Status Word to indicate Engine Ready Mode when system conditions satisfy requirements for Engine Ready in 3.2.1.1.4.5	180.0	

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TABLE XVIII(Concluded)

GENERAL NOTES

- φ1. The controller response for a failure to satisfy verification tests specified for this sequence shall be as defined in Table III.
2. Unless otherwise noted, functional operations once initiated, shall continue until changed by a subsequent operation, and tests made to verify a functional operation shall be terminated when the functional operation is negated.
3. Operations listed in this table shall be performed in the listed sequence and with the indicated timing. Where time for the operation is not stated the operation shall be performed in the least time practical after the previous operation.
- φ4. Verification of pressure level with a non-redundant sensor shall be performed by comparing the sensor output to a fixed voltage equivalent to the pressure level specified.

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TABLE XIX OPERATIONAL PROGRAM OPERATIONS MODE DEFINITIONS

Checkout	Start Preparation	Start	Mainstage	Shutdown	Post-Shutdown
<u>STANDBY</u> A waiting mode of controller operation during which active control sequence operations are not in process. Monitoring functions which do not affect engine hardware component status are continually active during this mode. Such functions include processing of vehicle commands, status update, controller self-test, and response to status requests from the vehicle.	<u>PURGE SEQUENCE NO. 1</u> First purge sequence of the Start Preparation phase is in progress. Functions include Oxidizer System and Intermediate Seal Purge operation.	<u>START INITIATION</u> Initial functions associated with the Start Sequence are in progress. These include all functions prior to ignition confirmed. <u>THRUST BUILDUP</u> ϕ Ignition has been detected by monitoring of Main Combustion Chamber Pressure; the thrust control loop has been closed, and closed-loop thrust buildup sequencing is in progress.	<u>NORMAL CONTROL</u> Mixture ratio control has been initiated. Thrust control is operating normally. Normal control functions are active. <u>THRUST LIMITING</u> ϕ Thrust is being limited by the temperature limit control. Other functions in progress are the same as for Normal Control.	<u>THROTTLING TO MPL</u> Shutdown is in progress at a programmed shutdown thrust reference level above MPL. <u>MPL TO ZERO THRUST</u> Shutdown is at a stage in the sequence where the programmed thrust reference has decreased below MPL. <u>PROPELLANT VALVES CLOSED</u> The shutdown sequence is in the stage following closure of all liquid propellant valves. Shutdown purge and verification sequences are in progress.	<u>STANDBY</u> A waiting mode of controller operation with functions identical to those of Standby during Checkout. This is the normal mode of Post-Shutdown entered after completion of the Shutdown phase. Other modes of the Post Shutdown phase may be entered from this mode. <u>OXIDIZER DUMP</u> The Oxidizer Dump sequence is being performed. <u>FUEL DUMP</u> The Fuel Dump sequence is being performed. <u>ABORT TURN-AROUND SEQUENCE NO. 1</u> Initial purge sequencing for
<u>PREFLIGHT CALIBRATION</u> ϕ Computation of key numbers for the calibration of performance control pressure sensors is in progress	<u>PURGE SEQUENCE NO. 2</u> Second purge sequence of Start Preparation is in progress. Functions include Fuel System Purge operation. <u>PURGE SEQUENCE NO. 3</u> Third purge sequence of Start Preparation is in progress. Functions include propellant recirculation. <u>PURGE SEQUENCE NO. 4</u> Fourth purge sequence of Start Preparation is in	<u>THRUST LIMITING</u> ϕ Thrust is being limited by the temperature limit control. Other functions of this mode are the same as for Thrust Buildup.			

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TABLE XIX (Continued)

Checkout	Start Preparation	Start	Mainstage	Shutdown	Post-Shutdown
<p><u>SEQUENCE CHECK ϕ</u></p> <p>A simulated start and shutdown sequence without propellants in the engine system is in progress. This checkout procedure verifies operation of the controller, sensors, engine control components and the vehicle/engine electrical interface.</p> <p><u>CHECKOUT COMPLETE ϕ</u></p> <p>A standby mode with functions identical to that of the Standby Mode except Pre-flight Calibration and Sequence Check must have been successfully completed with no subsequent failures detected by the monitoring functions.</p>	<p><u>PURGE SEQUENCE NO. 4 (Cont.)</u></p> <p>progress. Functions include Fuel System Purge after propellant drop.</p> <p><u>ENGINE READY</u></p> <p>The ready stage of Start Preparation in which proper engine thermal conditions for Start have been attained and other criteria for Start have been satisfied. Functions include a continuation of Purge Sequence No. 4 functions.</p>				<p><u>ABORT TURN-AROUND SEQUENCE NO. 1 (Cont.)</u></p> <p>Abort Turn-around is in progress.</p> <p><u>ABORT TURN-AROUND SEQUENCE NO. 2</u></p> <p>Propellant recirculation of Abort Turn-around is in progress.</p> <p><u>ENGINE READY</u></p> <p>The ready for start stage of Abort Turn-around has been attained in which proper engine thermal conditions for start exist and other criteria for start have been satisfied. Functions include continuation of Abort Turn-around Sequence 2 functions.</p>